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POTENTIAL INTERFERENCE TO 6 CM CONUS RADIO ASTRONOMY OBSERVATOR--ETC(U)

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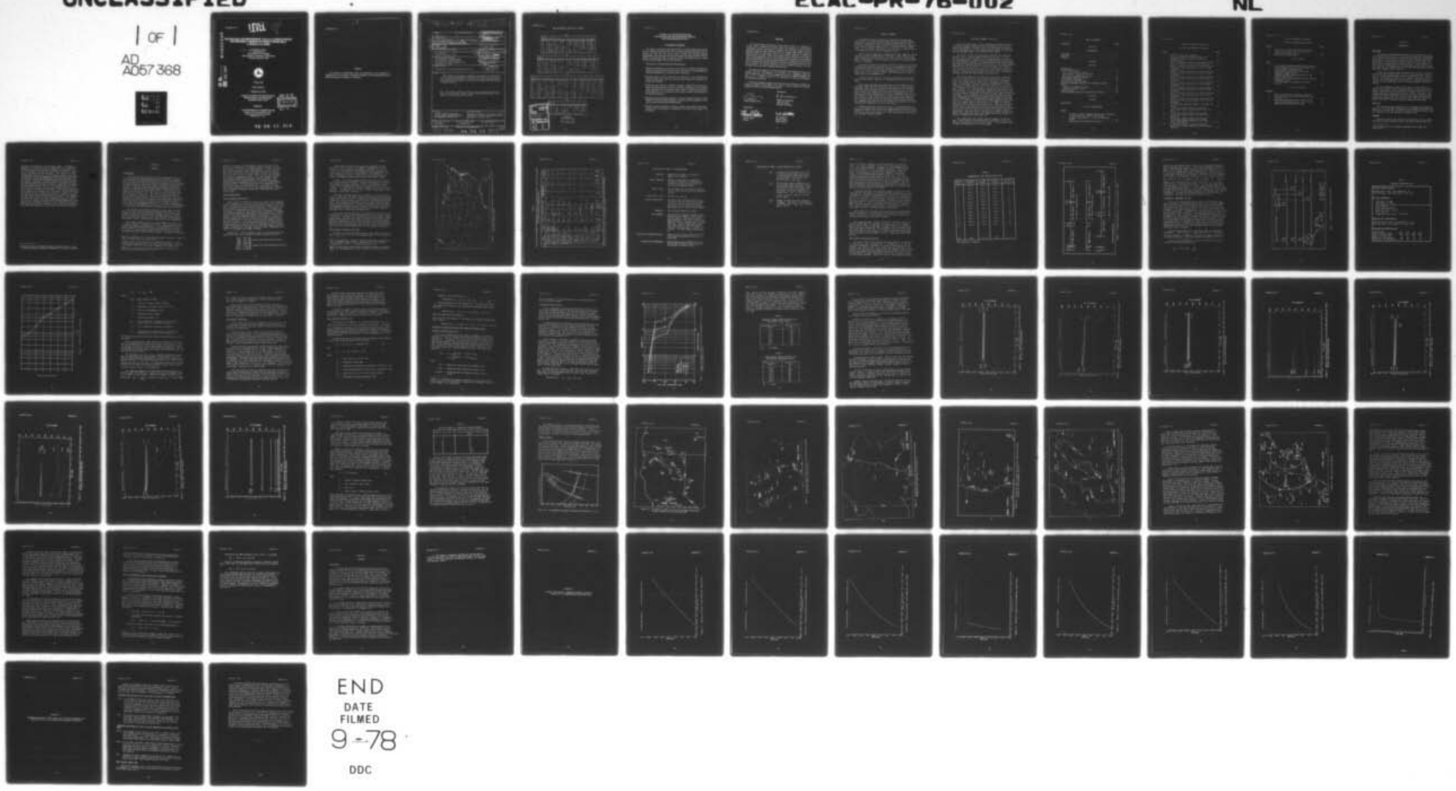

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POTENTIAL INTERFERENCE TO 6 cm CONUS RADIO ASTRONOMY OBSERVATORIES FROM MLS C-BAND A/G DME

IIT Research Institute
Under Contract to
DEPARTMENT OF DEFENSE
Electromagnetic Compatibility Analysis Center
Annapolis, Maryland 21402

January 1976

FINAL REPORT

Published June 1978

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, DC 20591

FAA-RD-77-111

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18 ECAC, FAA-RD

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16. Abstract

An analysis was performed to determine the potential for interference to radio astronomy observatories operating in the band 4.99-5.00 GHz from the C-band DME (air-to-ground) associated with the Time Reference Scanning Beam Microwave Landing System, as a function of proposed MLS DME frequency assignment plans.

Note: This report considers the MLS as it was at the time the study was done. Since that time, a number of design changes have been made. These changes are not addressed in this report.

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ENGLISH/METRIC CONVERSION FACTORS

LENGTH

From \ To	cm	m	km	in	ft	mi	nmi
cm	1	0.01	1×10^{-5}	0.3937	0.0328	6.21×10^{-6}	5.39×10^{-6}
m	100	1	0.001	39.37	3.281	0.0006	0.0005
km	100,000	1000	1	39370	3281	0.6214	0.5395
in	2.540	0.0254	2.54×10^{-5}	1	0.0833	1.58×10^{-5}	1.37×10^{-5}
ft	30.48	0.3048	3.05×10^{-4}	12	1	1.89×10^{-4}	1.64×10^{-4}
mi	160,900	1609	1.609	63360	5280	1	0.8688
nmi	185,200	1852	1.852	72930	6076	1.151	1

AREA

From \ To	cm^2	m^2	km^2	in^2	ft^2	mi^2	nmi^2
cm^2	1	0.0001	1×10^{-10}	0.1550	0.0011	3.86×10^{-11}	5.11×10^{-11}
m^2	10,000	1	1×10^{-6}	1550	10.76	3.86×10^{-7}	5.11×10^{-7}
km^2	1×10^{10}	1×10^{6}	1	1.55×10^{9}	1.08×10^{7}	0.3861	0.2914
in^2	6.452	0.0006	6.45×10^{-10}	1	0.0069	2.49×10^{-10}	1.88×10^{-10}
ft^2	929.0	0.0929	9.29×10^{-8}	144	1	3.59×10^{-8}	2.71×10^{-8}
mi^2	2.59×10^{10}	2.59×10^{6}	2.590	4.01×10^{9}	2.79×10^{7}	1	0.7548
nmi^2	3.43×10^{10}	3.43×10^{6}	3.432	5.31×10^{9}	3.70×10^{7}	1.325	1

VOLUME

From \ To	cm^3	liter	m^3	in^3	ft^3	yd^3	fl. oz.	fl. pt.	fl. qt.	gal.
cm^3	1	0.001	1×10^{-6}	0.0610	3.53×10^{-5}	1.31×10^{-6}	0.0338	0.0021	0.0010	0.0002
liter	1000	1	0.001	61.02	0.0353	0.0013	33.81	2.113	1.057	0.2642
m^3	1×10^{6}	1000	1	61,000	35.31	1.308	33,800	2113	1057	264.2
in^3	16.39	0.0163	1.64×10^{-5}	1	0.0006	2.14×10^{-5}	0.5541	0.0346	2113	0.0043
ft^3	28,300	28.32	0.0283	1728	1	0.0370	957.5	59.84	0.0173	7.481
yd^3	765,000	764.5	0.7646	46700	27	1	25900	1616	807.9	202.0
fl. oz.	29.57	0.2957	2.96×10^{-5}	1.805	0.0010	3.87×10^{-5}	1	0.0625	0.0312	0.0078
fl. pt.	473.2	0.4732	0.0005	28.88	0.0167	0.0006	16	1	0.5000	0.1250
fl. qt.	948.4	0.9463	0.0009	57.75	0.0334	0.0012	32	2	1	0.2500
gal.	3785	3.785	0.0038	231.0	0.1337	0.0050	128	8	4	1

MASS

From \ To	g	kg	oz	lb	ton
g	1	0.001	0.0353	0.0022	1.10×10^{-6}
kg	1000	1	35.27	2.205	0.0011
oz	28.35	0.0283	1	0.0625	3.12×10^{-5}
lb	453.6	0.4536	16	1	0.0005
ton	907,000	907.2	32,000	2000	1

TEMPERATURE

°F = 5/9 (°C - 32)

°C = 9/5 (°F) + 32

FAA-RD-77-111

FEDERAL AVIATION ADMINISTRATION
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
SPECTRUM MANAGEMENT STAFF

STATEMENT OF MISSION

The mission of the Spectrum Management Staff is to assist the Department of State, Office of Telecommunications Policy, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource--the electromagnetic radio-frequency spectrum.

This objective is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio-frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.

- Providing research, analysis, engineering, and evaluation in the development of spectrum related policy, planning, standards, criteria, measurement equipment, and measurement techniques.

- Conducting electromagnetic compatibility analyses to determine intra/inter-system viability and design parameters, to assure certification of adequate spectrum to support system operational use and projected growth patterns, to defend the aeronautical services spectrum from encroachment by others, and to provide for the efficient use of the aeronautical spectrum.

- Developing automated frequency-selection computer programs/routines to provide frequency planning, frequency assignment, and spectrum analysis capabilities in the spectrum supporting the National Airspace System.

- Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.

PREFACE

The Electromagnetic Compatibility Analysis Center (ECAC) is a Department of Defense facility, established to provide advice and assistance on electromagnetic compatibility matters to the Secretary of Defense, the Joint Chiefs of Staff, the military departments and other DoD components. The center, located at North Severn, Annapolis, Maryland 21402, is under policy control of the Assistant Secretary of Defense for Communication, Command, Control, and Intelligence and the Chairman, Joint Chiefs of Staff, or their designees, who jointly provide policy guidance, assign projects, and establish priorities. ECAC functions under the executive direction of the Secretary of the Air Force and the management and technical direction of the Center are provided by military and civil service personnel. The technical operations function is provided through an Air Force sponsored contract with the IIT Research Institute (IITRI).

This report was prepared for the Systems Research and Development Service of the Federal Aviation Administration in accordance with Interagency Agreement DOT-FA70WAI-175, as part of AF Project 649E under Contract F-19628-78-C-0006, by the staff of the IIT Research Institute at the Department of Defense Electromagnetic Compatibility Analysis Center.

To the extent possible, all abbreviations and symbols used in this report are taken from American Standards Y10.19 (1967) "Units Used in Electrical Science and Electrical Engineering" issued by the USA Standards Institute.

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Director

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Special Projects
Deputy Director

EXECUTIVE SUMMARY

The potential for interference to the Radio Astronomy (RA) band (4.990 to 5.000 GHz) within CONUS from the Microwave Landing System air-to-ground distance-measuring equipment (MLS A/G DME), operating in the band 5.001 to 5.250 GHz, was examined as requested by the Federal Aviation Administration. The DME's Service Volume limits are 20,000 feet (6100 meters) altitude and 20 nautical miles (37 kilometers) from a properly equipped airport.

Three separate frequency assignment plans were compared. Option 1 places the 200 A/G DME channels from 5001 to 5060.7 MHz and the angle information from 5128.0 to 5187.7 MHz. Option 6 interchanges the two allocations. Also considered was option 6 translated 30 MHz higher in frequency.

The only available out-of-band interference-protection threshold criterion for the Radio Astronomy service was suggested in the 1970 International Radio Consultative Committee (CCIR) document CCIR report 224-2. This is a CCIR Report recommendation, not a resolution, and as such is not binding. However, the USA generally attempts to comply with such recommendations.

A power density value of -141 dBm/m^2, suggested by the CCIR report, was used in this analysis as a reference value for the 5-GHz band.

Most of the ten Radio Astronomy Observatories (RAO) presently using the 4.990-5.000 GHz RA band use receivers with predetection bandwidths wider than the allocated band (between 10 and 250 MHz). Also, the center tuning frequency of some RAO receivers is outside this RA band. This analysis accounts for in-band potential interference, using four representative receiver bandwidths (250, 50, 30, and 10 MHz). It was assumed that each RAO receiver was tuned such that the upper 3 dB selectivity point was aligned with 5.000 GHz. This analysis deals mainly with the sidelobe-to-sidelobe condition, and recommends that any mainlobe-to-mainlobe and mainlobe-to-sidelobe conditions be examined on a case-by-case basis.

Frequency-distance curves for each receiver bandwidth and frequency plan option were calculated, using a smooth-curve smooth-earth propagation model, based on the -141 (dBm/m^2) CCIR criterion. Within each plot, curves were provided for seven combinations of propagation loss and DME transmitter power.

EXECUTIVE SUMMARY (Continued)

Option 6, which allows a greater frequency separation between the radio astronomy band and the A/G DME channels, proved to be better than option 1. Because of the wide bandwidths and shallow fall-off characteristics of the RAO receivers, option 6 showed only slight improvement when it was shifted 30 MHz higher.

The results of the F-D calculations indicate that, for both options 1 and 6, large distance separations (120 nmi, [222 km]) are necessary if the -141 dBm/m^2 CCIR recommendation is to be met for wide bandwidth (250 MHz) radio astronomy observations when five or more aircraft equipped with C-Band MLS DME operate simultaneously. Much smaller separation distances are required if the radio astronomy bandwidth does not exceed the allocated spectrum. The effects of local terrain shielding from an aircraft at 20,000 feet (6100 m) were calculated, and plots showing 20,000 foot (6100 m) acquisition contours, together with representative airports that are probable candidates for the MLS DME system, were generated.

The terrain features near the western RAO sites, in general, decreased the potential for interference through shielding, especially if channels near the upper end of the option 6 frequency limit were assigned and the RAO receivers remained tuned within their allotted band. The worst potential interference situation examined was in Massachusetts, where three RAO sites are situated close together and all are within 25 nautical miles (46 km) of two major airports. Any wide-bandwidth, shallow-fall-off RAO receiver in this locale, or in any other area congested with MLS where there is little terrain shielding, will almost certainly require additional filtering. This is especially true if several MLS DME's are operated simultaneously and the CCIR-suggested power density threshold is to be maintained. Disregarding the existing RAO receiver bandwidths, it is possible to reduce the A/G DME transmitter power density at the upper edge of the RA band to -141 dBm/m^2 by adding a high-pass filter to the airborne transmitter. The required attenuation value of the high-pass filter at 5.0 GHz would be between 38 and 50 dB, depending upon the allowable deterioration of the DME transmitter pulse rise time and the separation distance mutually agreed upon. With this filter installed, any further in-band interference reduction would have to be accomplished within the RAO receivers as suggested by CCIR report 547.

This report does not consider the cost impact of filtering. With a large number of airborne MLS DME interrogators, even an inexpensive filter could have a serious impact. It is doubtful that the FAA could mandate the use of filtering.

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SECTION 1

INTRODUCTION

BACKGROUND

The Federal Aviation Administration (FAA) has proposed a Microwave Landing System (MLS) as the standard national and international system to meet military and civilian non-visual approach and landing requirements. The system will operate in the 5.001-5.250 GHz frequency band, and will provide angle guidance and slant range to the runway for all appropriately equipped aircraft. Angle guidance is provided with a time-reference scanning-beam technique, while range and range-rate are obtained with an interrogator/transponder distance-measuring equipment (DME) technique.

Because the allocated Radio Astronomy Band (4.990 to 5.000 GHz) adjoins the MLS frequency band, the FAA is concerned about the possibility of MLS interference to Radio Astronomy Observatory (RAO) receivers. Of particular interest is the DME air-to-ground link, because of the large geographic area affected by transmissions from an aircraft at the 20,000-foot (6100 m) ceiling of the MLS operating volume.

The Electromagnetic Compatibility Analysis Center (ECAC) was tasked by the Federal Aviation Administration[1] to determine the potential interference to the CONUS Radio Astronomy Observatories, operating within the radio astronomy band (4.990 to 5.000 GHz), from airborne MLS DME interrogators using the frequency assignment plan in the 5128.0-5187.7 MHz band (option 6) and compare this with the frequency assignment plan in the 5001.0-5060.7 MHz band (option 1), and the 5158-5217.7 MHz band (option 6 translated up 30 MHz).

OBJECTIVE

The objective of this analysis was to determine the interference potential of the MLS DME interrogators to the CONUS RAO receivers operating in the 4.990 GHz to 5.000 GHz Radio Astronomy frequency band, as a function of the MLS frequency assignment plan.

APPROACH

Once the locations and technical characteristics of the CONUS-based RAO receivers operating within the 4.990-5.000 GHz band were

[1] Task Assignment 29 of Interagency Agreement DOT FA 70WAI-175, March 1975.

obtained, an interference criterion was sought. Although the appropriate OTP and FCC rules and regulations were examined, an International Radio Consultative Committee (CCIR) report[2] was the only document that specifically defined interference limits within the Radio Astronomy (RA) bands. This report is a CCIR recommendation and as such, is not binding. However, using the interference criterion recommended by the CCIR, the total power loss between the MLS DME transmitter and the RAO receiver was calculated. After the interference conditions were established, the frequency-dependent rejection (FDR) was calculated for the MLS DME transmitter and RAO receivers as a function of frequency assignment plan options 1 and 6. The frequency-distance (F-D) curves necessary to meet the required coupling loss were generated using the FDR data for each option. Conclusions were drawn after examining and comparing the F-D curves. The possibility of shifting the option 6 channel plan upward in frequency by 30 MHz was considered, and the frequency-distance curves were compared with the curves plotted for the original option 6. To ascertain the effect of terrain shielding on separation distance, radio line-of-sight contours for some Radio Astronomy Observatory (RAO) stations were plotted and analyzed. Where little or no terrain shielding was available, the possibility of additional filtering on the MLS DME transmitter and the RAO receiver was considered.

[2]Documents of the XII Plenary Assembly, Volume IV Annex 1, 1970 International Radio Consultative Committee, New Delhi, ITU 1970.

SECTION 2

ANALYSIS

INTRODUCTION

The locations and the majority of system characteristics of the operating radio astronomy observatories within the contiguous United States were obtained primarily from the 1974 publication, *Radio and Radar Astronomy Observatories*, promulgated by the Committee on Radio Frequencies, National Academy of Sciences, Washington, DC. The data on the Very Large Array (VLA) installation near Socorro, New Mexico, operated by the National Radio Astronomy Observatory (NRAO), was obtained from published data[3,4,5], and where more information was necessary, from phone conversations with NRAO scientists working on the project. The emission spectrum for the MLS DME was supplied by the FAA. The emission spectrum envelope of the MLS DME and representative RAO receiver selectivity curves were combined to determine the FDR between the airborne DME transmitter at an altitude of 20,000 feet and the radio astronomy receivers. To account for the bandwidth variations in the radio astronomy receiver, four typical bandwidths were used. FDR curves were generated as a function of MLS DME frequency assignment plan options 1 and 6.

The FDR data, the airborne transmitter power output, antenna gains, the power density limitation desired at the receiver, and propagation path loss were combined to produce a set of frequency-distance curves as a function of the required total power loss between the transmitter and receiver. This was done for MLS channel plan options 1 and 6 with each of the four RAO receiver bandwidths.

Only single, parabolic-dish receiving antennas were used so as to keep the analysis as general as possible. Some observatories do use multiple-antenna interferometers. An interferometer is an economical method of increasing the effective aperture of an antenna by using two or more smaller antennas with parallel boresite axes, and separating them by some baseline distance. Although the far-field

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[3]*The VLA, A Proposal For a Very Large Array Radio Telescope*, Volume III, NRAO, Greenbank, West VA, January 1969.

[4]Pieper, Brian V., *An Identification of Potential Sources of Radio Frequency Interference to the Very Large Array (VLA) Radio Telescope*, Final Report, ECAC-PR-73-056, ECAC, Annapolis, MD, January 1974.

[5]Napier, P. J., *The Effect of Radio Interference on the VLA*, VLA Electronics Memo #110, March 28, 1973.

patterns illuminate the same volume in space, the angle of arrival may be determined by noting the phase difference between the signals arriving at the separate antennas. As with any wide-spaced multiple-antenna array, the composite far-field pattern due to the interaction of the individual far-field antenna patterns will form a series of lobes, which in optics are referred to as fringes, separated by nulls. For large baseline spacing the composite pattern will have many lobes or fringes. Consequently, the use of interferometers will inherently provide some additional interference rejection within the interferometer fringing pattern. This additional rejection is dependent on a multitude of factors, some of which are: the number of fringe lobes and the pointing direction of the fringing pattern, and the speed, separation distance and altitude of the potential interfering source.

SYSTEM DESCRIPTIONS

Radio Astronomy Observatories

RAO's can be classified into two types. Class A observatories receive information from relatively high intensity cosmic radiations. Class B observatories, with which this analysis deals, receive very weak extra-galactic signals that resemble noise. These RAO's also can be further categorized by mode of observation: broadband observations, in which the total power within a passband is measured (continuum measurements), and spectral-line observations, in which intrinsically narrowband measurements are made over a range of frequencies. Receiver bandwidths for this last mode are relatively narrow, ranging from 1 kHz to 10 MHz, and are determined mainly by the characteristics of the source observed and any Doppler effects that may be present. In continuum measurements, the achievement of maximum sensitivity requires the use of the largest possible bandwidths (consistent with rejection of out-of-band signals), low-noise parametric amplifiers, and long integration times. Bandwidths presently in use range from 10 MHz to 250 MHz.

Within the 1 - 25 GHz frequency range, the following seven frequency bands have been allocated to Radio Astronomy by the OTP.

1400 - 1427 MHz
1660 - 1670 MHz (shared with Meteorological Aids)
2690 - 2700 MHz
4990 - 5000 MHz
10.68 - 10.70 GHz (shared with Fixed and Mobile Services)
15.35 - 15.40 GHz
23.60 - 24.00 GHz

These bands are protected to the extent specified by footnotes US74, US99, and G45 to the Manual of Regulations and Procedures for Radio Frequency Management of the OTP. In addition to this list of frequencies, the OTP and FCC have designated an area in West Virginia as a "quiet zone"[5,6] (see APPENDIX B). This area is bounded by 39°15'N, 78°30'W, 37°30'N, and 80°30'W which encloses the NRAO and Naval Radio Research Observatory (NRRO).

Figure 1 shows the geographical locations of the observatories in the contiguous United States, including the NRAO VLA in Socorro, NM, scheduled to begin operation in 1976. Also included is the "quiet zone" surrounding the NRAO at Greenbank, West VA. Listed in TABLE 1 are the pertinent technical characteristics of these observatories. The numbering of the sites in TABLE 1 corresponds to the numbering of the sites in Figure 1.

The radio astronomy band under consideration, (4.99-5.00 GHz) is only 10 MHz wide, but TABLE 1 shows that not only do many astronomy receivers have a variety of predetection bandwidths greater than 10 MHz, but also that some are tuned outside the protected astronomy band. These conditions precluded any one of these radio astronomy stations from being used as a typical installation, and also forced the fundamental approach that the potential interference being considered would be limited to that occurring at or below 5.000 GHz, the upper limit of this radio astronomy band.

Due to the inherent insertion-loss properties of filters, Class B observatories, striving for the most gain, use as little filtering as possible. Therefore, the characteristics of the parametric amplifier determine the main slope fall-off beyond the pass band. Unless definite information to the contrary existed or a filter of known properties was being used, the slope fall-off of the radio astronomy receivers used in this analysis was 40 dB per decade, which approximates the slope fall-off characteristics of a parametric amplifier.

FAA Microwave Landing System (MLS)

The MLS, an aircraft nonvisual approach and landing system, operates within the 5.0 to 5.25 GHz frequency band. It is a system in

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[5]Rules and Regulations, Volume II Federal Communication Commission, U.S. Government Printing Office, Washington, DC, May 1966 and Amendments No. II (66) - 1 through 13, Section 5.69.

[6]Manual of Regulations and Procedure for Radio Frequency Management, Office of Telecommunication Policy, Chapter 8, Section 8.4.9, rev. 9/74.

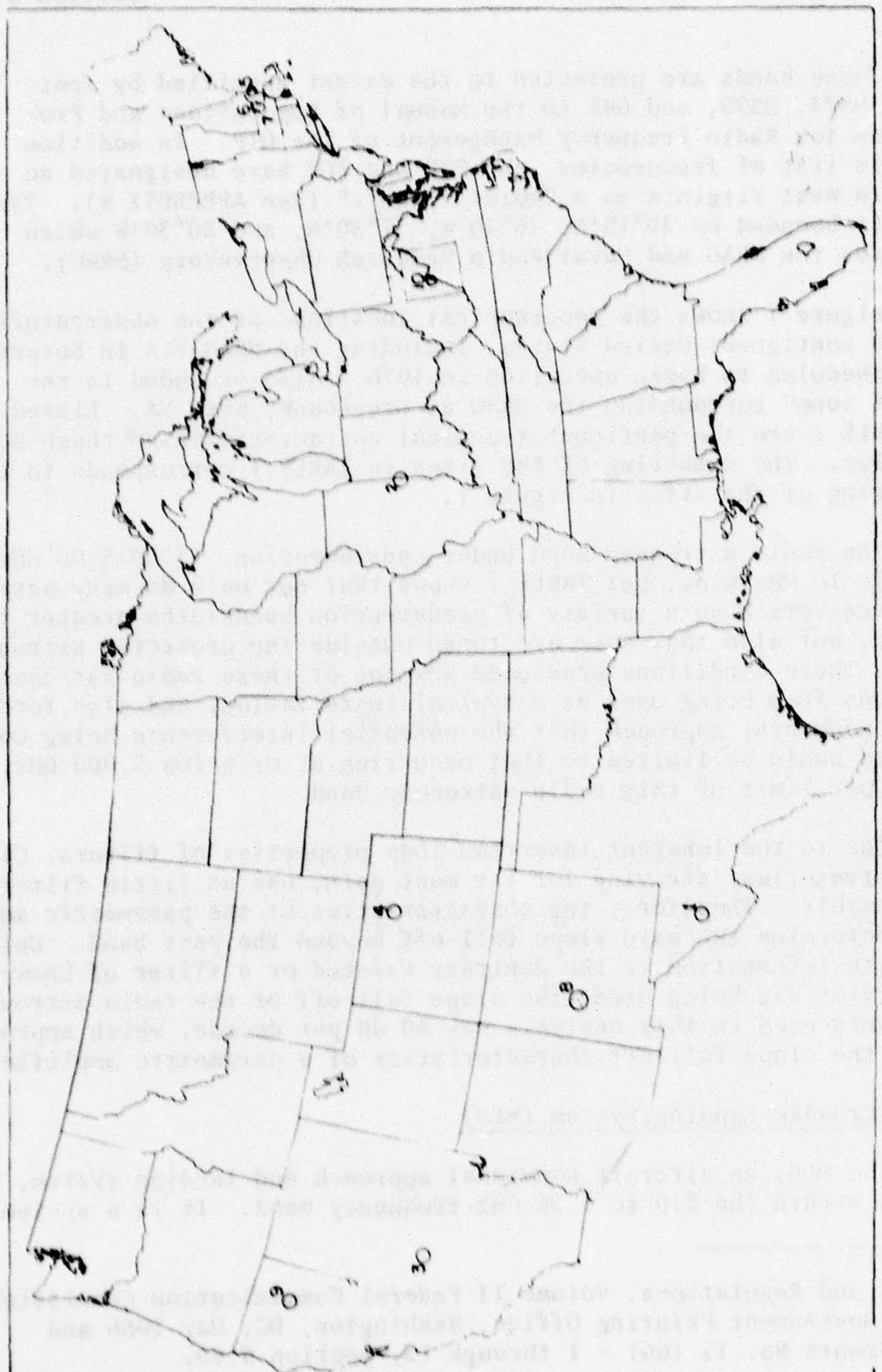

Figure 1. Location of radio astronomy observatories operating in and/or near the 4.990-5.000 GHz band.

TABLE 1

LIST OF RADIO ASTRONOMY OBSERVATORIES OPERATING IN AND/OR NEAR THE 4.990-5.000 GHz BAND, AND THEIR TECHNICAL CHARACTERISTICS

Site No.	Name Location Operating Admin.	Type & Class of Observations	Antenna Size & Type	Antenna Polarization	Freq.[a] (MHz)	Sky Coverage	Predetection Bandwidth (MHz)	System Noise Temperature (°K)	Δ Te (°K)	Δ Ph (dBm)	S_H^B (dBm/m^2)
1	Harvard Radio Astr. Obs Fort Davis Texas 30°38'08"N, 103°56'42"W Howard University	Extragalactic Spectral Line & Continuum Class, B	85 ft. Parabolic	Linear	5010	Full Sky	30	250	7.22 x 10^{-4}	-165.2	-129.81
2	Vermillion River Obs. Danville Illinois 40°03'38"N, 87°33'49"W University of Illinois Urbana, Illinois 61801	Extragalactic Spectrum Line Galactic & Continuum Galactic Class, B	120 ft. Parabolic	Rotational Linear & Both Circular Modes	4995	HA = 3 hr DEC - 10° to + 80	20	300	1.06 x 10^{-3}	-165.3	-130.0
3	Owens Valley Radio Obs. Big Pine, Calif. 37°13.9'N, 118°17.6'W Calif. Institute of Tech.	Line & Continuum	90 ft. Parabolic	Linear Rotating	4995	H.A. = Full Sky DEC = -37° to +80°	.001-20	120	4.24 x 10^{-4}	-169.3	-133.9
4	Table Mtn. Radio Obs. Boulder Colorado 40°05'28"N, 105°07'21"W Space Environmental Lab. NOAA, Boulder Colo 80302	Solar Class, A	8 ft. Parabolic	Linear	4995	H.A. Full Sky DEC ± 40°	10.	300	1.50 x 10^{-3}	-165.8	-131.4
5	Sagamore Hill Radio Obs. Hamilton, Mass. 42°37'54"N, 70°49'15"W U.S.A.F. AFCRL (LIR) L.G. Hanscom Field Bedford, Mass. 01730	Solar Patrol Class B	8 ft. Parabolic	Linear Vertical at HA = 0h	4965 5025	H.A. Full Sky DEC ± 30°	16 16	1000 1000	3.95 x 10^{-3}	-160.6	-125.2
6	Haystack Obser. Tyngsboro, Mass. 42°37'23"N, 71°21'19"W Northest Radio Obs. Corporation Westford, Mass. 01886	H_2CO Line Mapping Class B	118 ft. Parabolic	Linear or Circular	4830	Full Sky	30	350	1.01 x 10^{-3}	-163.8	-128.4
7	Geo. R. Agassi Station Harvard Mass. 42°30'13"N, 71°33.6'W Harvard University	Spectral Line Class B	84 ft. Parabolic Equatorial Mount	unknown	4750	H.A. = -6h - +7h	200	250	2.80 x 10^{-4}	-161.125	-125.7
8	Very Large Array Socorro N.M. 34°04'44"N, 107°37'03"W NRAO Charlottesville, Va.	Extragalactic Line & Continuum	82 ft. Parabolic	Circular	4990-5000	H.A. ± 6h DEC to +88°	50	50	1.12 x 10^{-4}	-171.1	-135.7
9	Hat Creek Radio Astr. Sta. Cassel Calif. 40°49'03"N, 121°28'24"W University of California Berkeley, Calif. 94720	Line & Continuum Class B	85 ft. Parabolic	unknown	4750-5250	Full Sky	16.6	50	1.94 x 10^{-4}	-173.5	-138.1
10	National Radio Astr. Obs. Greenbank, W. Va. 38°26'08"N, 79°44'42" NRAO Greenbank W. Va.	Continuum Continuum Line & Continuum Interferometer H_2 Line, Continuum Line Observation	300 ft. Parabolic 140 ft. Parabolic 385 ft.	Variable Variable	4995 5000 4500-5000. 4600-5100. 5000. 5200-10400.	H.A. = 0hr DEC - 20° - + 86° H.A. ± 6h DEC -48° to +88	30 200 250 20 400 40	120 130 100 150 50 300	3.46 x 10^{-4} 1.45 x 10^{-4} 1.0 x 10^{-4} 5.3 x 10^{-4} 3.95 x 10^{-5}	-168.4 -164.0 -164.6 -168.3 -166.6	-133.0 -128.5 -129.7 -133.0 -131.2

[a] Radio astronomy receivers, like most passive devices, do not interfere with other services. Consequently, they may operate outside their authorized bandwidth. Most of the observatories listed here do so. Due to the severe operating constraints which would result, the FAA cannot consider frequency protection for that part of such radio astronomy observations that fall outside the authorized bandwidth.

Explanation of TABLE 1 Column Headings

SITE NO. :	Arbitrary site number to correlate TABLE 1 with Figure 1.
NAME & LOCATION :	The name of the Radio Astronomy Observatory followed by its geographical location (latitude and longitude) and the operating administration.
TYPE & CLASS :	Type and Class of observations conducted in the 4.990-5.000 GHz band, as explained in text.
ANTENNA SIZE & TYPE :	Antenna size and type.
ANTENNA POLARIZATION :	Generally radio astronomy antennas are adjustable such that they may be changed at will to receive circular or linear (horizontal or vertical) polarizations depending upon the interest at the moment.
FREQUENCY :	The operating frequency(s) (MHz).
SKY COVERAGE :	That portion of the sky included in the observation as bounded by the declination and hour angles. Declination is that angle measured at the center of the earth from the celestial equator north or south. Hour Angle, usually understood to mean local hour angle, is measured from the observer's meridian east (-) or west (+) in hours. One hour roughly approximates 15°.
PREDETECTION BANDWIDTHS (MHz) :	These are the receiver bandwidths before final detection (generally the last IF bandwidth).
SYSTEM NOISE TEMPERATURE :	The equivalent noise temperature of the overall RAO receiving system, including the antenna, in degrees Kelvin.

Explanation of TABLE 1 Column Headings (Continued)

ΔTe : As defined in CCIR report 224-2, ΔTe is the root mean square fluctuation of operating noise temperature about its mean value. (See page 17 for definitions of T_a and T_{eff}.)

ΔP_H : The root mean square fluctuation of total harmful power expressed in terms of operating noise temperature, which fluctuates in time in accordance with the normal statistical properties of random noise. $\Delta P_H = 0.1$ kB (ΔTe) watts or $\Delta PH = -208.6 + 10 \log B + 10 \log (\Delta Te)$, (dBm).

$S_H B$: Harmful interference level expressed in dBm/m^2. (See page 17 for definition of harmful level.) $S_H B = P_H + 20 \log f$ (MHz) - 38.6.

which the position information is measured directly in the aircraft. The ground equipment consists of an angle-guidance transmitter and a DME transponder. Equipment on the aircraft consists of an angle-guidance receiver and DME interrogator. Angle information is provided by a time-reference scanning-beam technique where a narrow-beamwidth antenna pattern sweeps a narrowband signal to and fro across the desired coverage area. The time difference between the signal received on the "to" scan, and the signal received on the "fro" scan is directly proportional to the angle deviation from the runway center line for azimuth and to the angle measured with respect to the ground for elevation. The airborne DME measures the time between its interrogation transmission and its reception of the ground-transponder reply to determine range from the touch down point on the runway.

In the DME operation, the aircraft transmits a pulse pair with a spacing that identifies it to the ground DME transponder as a valid interrogation. The ground transponder will decode this information, and after a fixed delay, transmit a pulse pair with the same spacing back to the aircraft. This ground reply frequency will be about 60 MHz above or below the received frequency, depending on the frequency plan (see TABLE 2). Since the fixed time delay in the transceiver is known, the only variable in the delay encountered by the signal is the propagation time, one half of which is converted directly into slant range distance by the DME airborne interrogator.

Operational use of the DME will be restricted to approaching or departing aircraft at or below 20,000 feet and within 20 nmi of the airport. However, it is not unusual for the pilot to turn on the interrogator outside of the service volume.

MLS Frequency Plans. Option 1 refers to a frequency plan which assigns the MLS DME air-to-ground (A/G) operation to the frequency band from 5001.0 MHz to 5060.7 MHz. Option 6 refers to a second frequency plan which assigns the DME A/G channels to the frequency span from 5128.0 MHz to 5187.7 MHz. An alternate to option 6 would shift the DME frequencies 30 MHz higher. Figure 2 shows these assignments, along with those for the ground-to-air (G/A) operation and the angle guidance.

DME Airborne Transmitting System

The power output of the airborne DME transmitter is +55 dBm peak (11 dBm average), and the antenna has a mainbeam gain of 11 dBi with a 26-degree beamwidth. The DME A/G frequency plans provide 200 DME channels, each 300 kHz wide. This channel spacing of 300 kHz relies on pulse-pair spacing discrimination to reject adjacent-channel signals. The time difference from the leading edge of the first pulse to the leading edge of the pulse following is the pulse-pair spacing, which is varied among channels. There is at least a 6-μs spacing difference

TABLE 2

REPRESENTATIVE DME CHANNELIZATION PLAN

Channel Number	A/G Option 1 Frequency[a]	G/A DME Frequency	A/G Option 6 Frequency	DME Pulse Spacing (μs)
0	5001.0	5067.9	5128.0	12
1	5001.3	5068.2	5128.3	20
2	5001.6	5068.5	5128.6	26
3	5001.9	5068.8	5128.9	14
4	5002.2	5069.1	5129.2	22
5	5002.5	5069.4	5129.5	28
6	5002.8	5069.7	5129.8	16
7	5003.1	5070.0	5130.1	24
8	5003.4	5070.3	5130.4	30
9	5003.7	5070.6	5130.7	18
10	5004.0	5070.9	5130.0	12
11	5004.3	5071.2	5131.3	20
12	5004.6	5071.5	5131.6	26
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
199	5060.7	5127.6	5187.7	18

[a]All frequencies in megahertz.

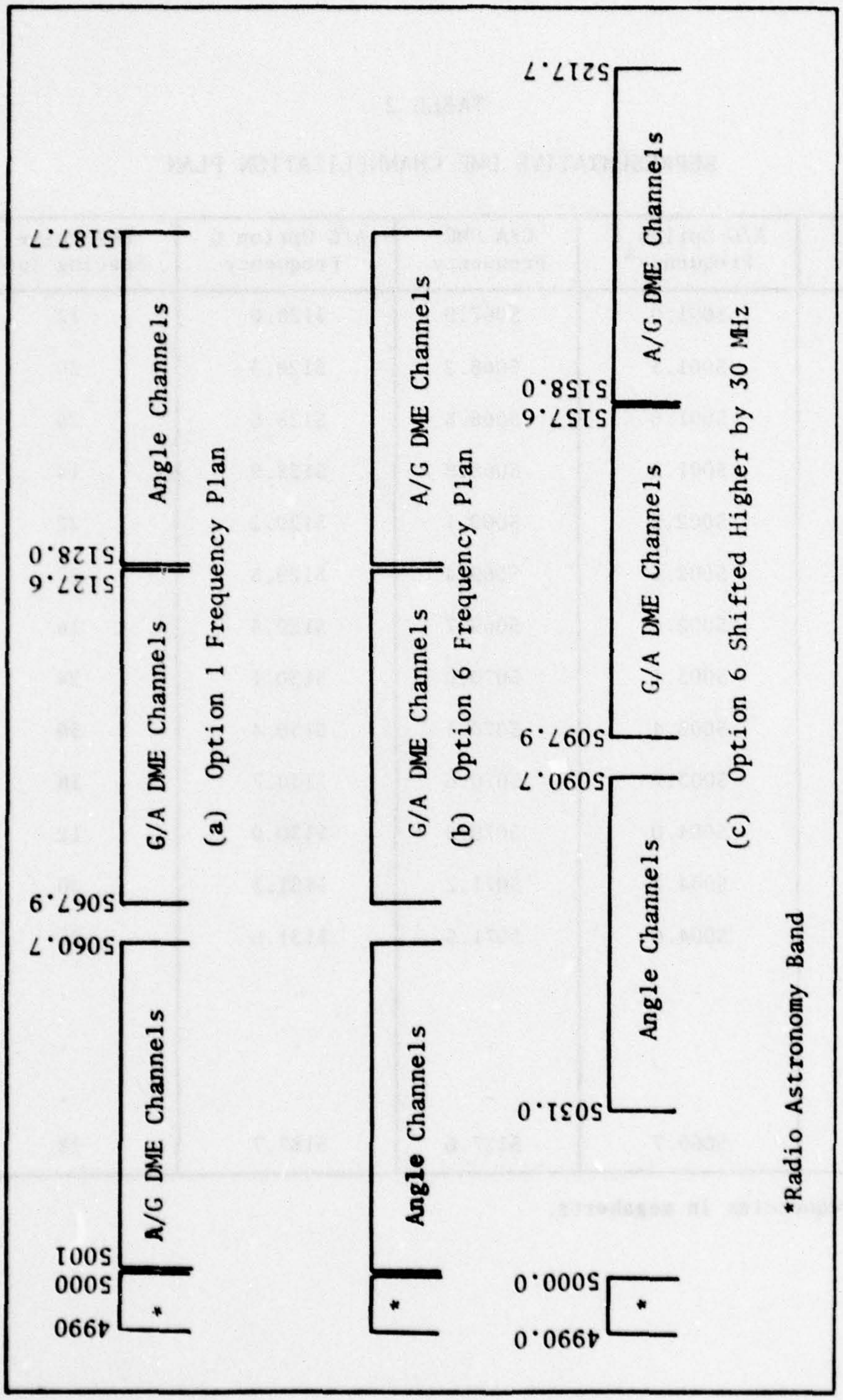

Figure 2. Frequency plan option 1, 6, and 6 up-shifted 30 MHz

between adjacent channels and at least a 4-μs spacing difference between second-adjacent channels. Two channels separated by 900 kHz (three channels apart) have a pulse pair spacing difference of 2 μs. TABLE 2 lists the DME channel plan frequencies for both option 1 and 6, along with representative pulse pair spacings. Figure 3 shows a representative DME pulse pair spacing. Using the first four channels as an example, t for channel 0 would be 12 μs; Δt_1 between channel 0 and 1 would be 8 μs, Δt_2 equals 4 μs and Δt_3 equals 2 μs. The pulse shape is also shown in Figure 3; pulse rise time is 0.1 μs, pulse width is 0.66 μs, and pulse fall time is 0.33 μs. The pulse repetition frequency is between 30 and 40 pps. The technical parameters used are summarized in TABLE 3. It was assumed in this analysis that the emission spectrum from the airborne DME transmitter was essentially constant within its tuning range, regardless of the pulse-pair spacing transmitted. The emission spectrum envelope for the DME airborne transmitter, obtained from the FAA, is shown in Figure 4.

INTERFERENCE THRESHOLD CRITERIA

There are two interference levels that are of concern to the radio astronomer: strong interference, which can be noticed immediately, and low levels of interference that are not easily noticed. The interference level that is obvious to the monitoring/recording equipment or to observing personnel is, of course, undesirable, but it can be coped with. A combination of factors such as the type, level, and duration of the interference, the observing equipment used, and the particular study in progress, will determine how serious the interference is. The ultimate consequence of obvious interference would be that the entire observation results would be discarded. Usually it is necessary to discard only the time interval during which the interference occurs. Interference levels that are not detected or detectable, but are of sufficient strength to cause invalid or misleading conclusions to be accepted and published, are the greatest problem for radio astronomy.

The CCIR report (Reference 2) specifies that, for continuum measurements in the 5 GHz (6 cm) radio astronomy band, assuming an isotropic antenna, -141 dBm/m^2 is the level of signal, measured at the antenna terminals, above which harmful interference will occur.

The value of -141 dBm/m^2 as listed in the CCIR report was arrived at by the following formulas:

$$S_H B = 0.1\ k\ B\ (\Delta T_e)\ \frac{c^2}{4\pi f^2} \qquad (1)$$

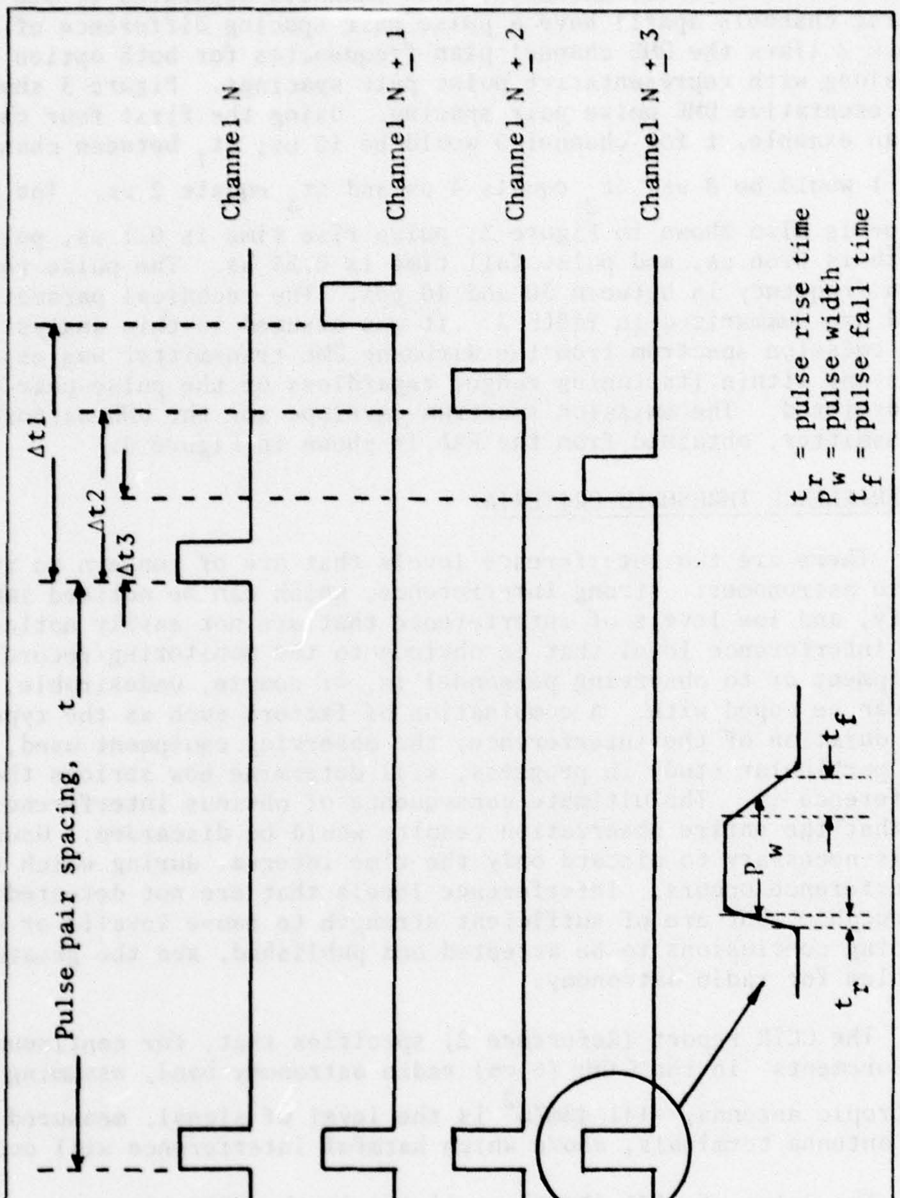

Figure 3. Representative A/G DME pulse spacing.

TABLE 3

TECHNICAL PARAMETERS USED

MLS DME Airborne Antenna

Mainbeam gain 11 dBi, 3-dB beamwidth = 26°
Side lobe gain = back lobe gain = 0 dBi, 334°

MLS DME Transmitter

Peak power = 55 dBm
Avg. power = 11 dBm
3-dB bandwidth = 1.2 MHz (see Figure 4 for emission spectrum)
Pulse width = 0.66 μs
Pulse rise time = 0.1 μs
Pulse fall time = 0.33 μs
PRF = 30 pp/s
Transmitter noise level = 71 dB down

Representative RAO Antenna

Mainbeam gain 55.5 dBi, 3-dB beamwidth = 1.5°
Side lobe gain = back lobe gain = 0 dBi, 358.5°

Representative RAO Receivers

3-dB BW (MHz)	250	50	30	10
Center frequency (MHz)	4875	4975	4985	4995
Image rejection (dB)	80	80	80	80
Spurious rejection (dB)	60	60	60	60
Slope fall off (dB/decade)	40	80	40	40

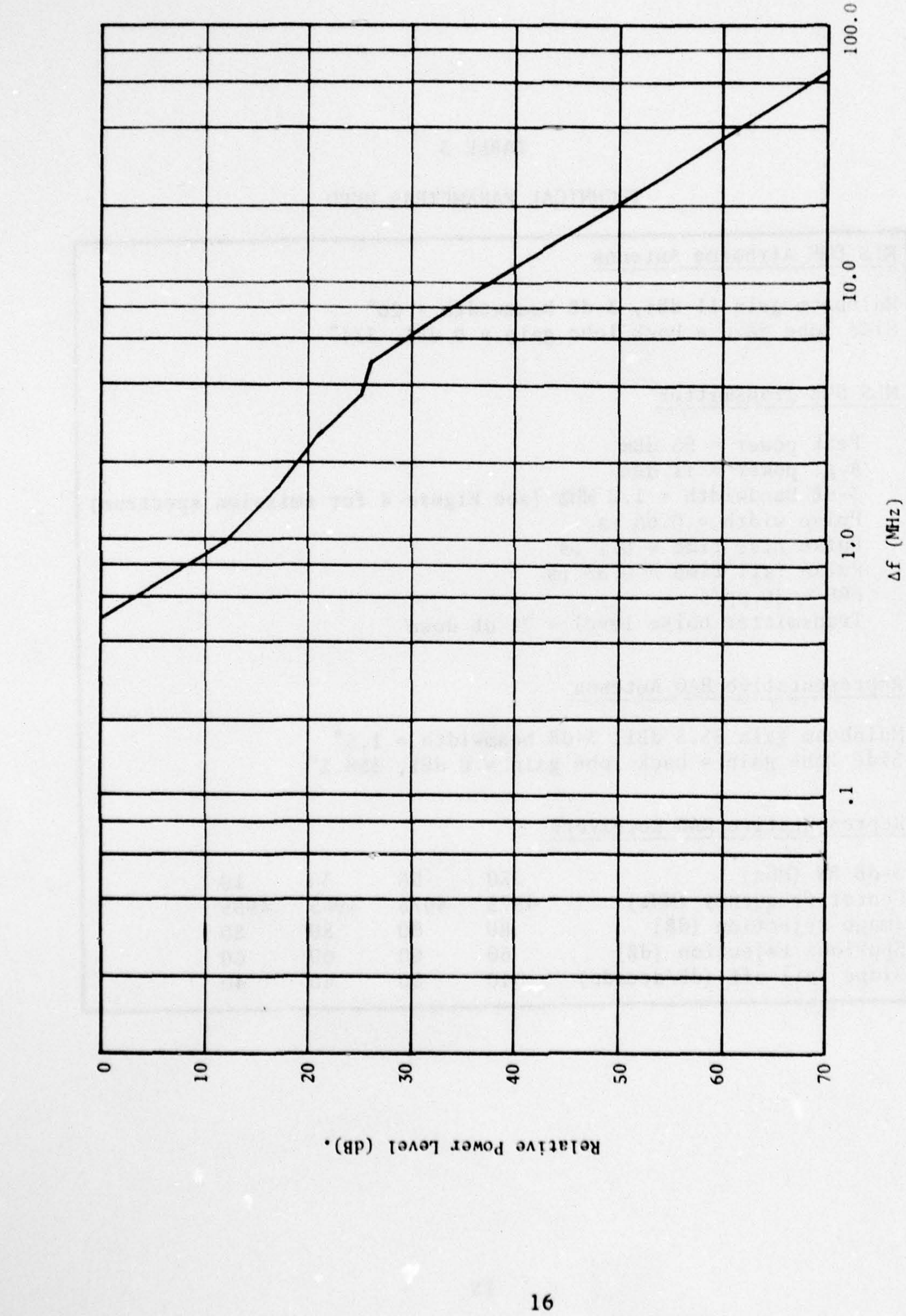

Figure 4. MLS-DME A/G emission spectrum.

$$\Delta T_e = \frac{T_a + T_{eff}}{\sqrt{2Bt}} \qquad (2)$$

where

$S_H B$ = power density in W/m^2

c = velocity of light (2.998×10^8 m/s)

k = Boltzmann's constant (1.38×10^{-23} J/K)

B = receiver 3-dB bandwidth in Hz

t = integration time, seconds

f = radiating frequency, Hz

T_{eff} = noise temperature component due to receiving system, referred to antenna terminals, K

T_a = noise temperature entering via antenna, K

ΔT_e = root mean square fluctuation of system noise temperature (T_e) about its mean value, K.

The integration time used was 2000 seconds; no justification for this was given.

Most extraterrestrial cosmic emissions of interest to Class B radio astronomy observatories have noise-like characteristics. Thus the inherent uncertainty of their measurement is limited or fixed by fluctuations of the total noise, both desired and undesired. These fluctuations are usually expressed in terms of an equivalent rms temperature fluctuation (ΔT_e).

The CCIR report also states that: "Harmful interference occurs when the unwanted signal flux impinging on the antenna is so great that the operating noise temperature is increased by an amount comparable with ΔT_e. If the radio astronomy service is to secure the advantages of low-noise receivers, the interference should not introduce an error of more than 10% in the measurement of ΔT_e". This is the reason for the 0.1 factor in the Equation 1.

For comparison purposes, the same 2000-second integration time that was used in the CCIR 224-2 report was used in the computation of ΔT_e in TABLE 1 of this report. Expressed in dBm/m^2, Equation 1 can be written: $S_H B = -208.6 + 10 \log B + 10 \log (\Delta T_e) + 20 \log f \text{ (MHz)} - 38.6$

This formula was used to calculate the power density for each of the 10 radio-astronomy observatories, and the resulting values are shown in Column 12 of TABLE 1.

Conversations with radio astronomy scientists, however, revealed that these levels (Column 12, TABLE 1) may not be immediately detectable, while interference levels 20 to 30 dB above these levels would be immediately detectable and therefore not quite so injurious. Therefore, in computing the frequency-distance requirements, based upon the FDR and total propagation loss, the change in the separation distance requirement was examined for various total loss values.

INTERFERENCE CONDITIONS

In this report, the potential interference prediction for analysis purposes was based upon the assumption that the RAO station antennas could entirely cover the visible sky and the aircraft had unrestricted flight paths.

Assuming for this analysis that sidelobe and backlobe gain levels are indistinguishable, three significant gain-coupling conditions are possible between an airborne MLS DME and an RAO receiver. The first is mainbeam-to-mainbeam coupling, when the aircraft flight path is aligned with the boresight of the RAO antenna. Second, MLS DME sidelobe energy can impinge on the main beam of an RAO receiver antenna. Third, sidelobe-to-sidelobe coupling can exist.

A typical RAO station parabolic antenna might easily have a gain of 55 dBi with a 3-dB beamwidth of 1.5° and a 0-dBi beamwidth of 8°, (that is, 8° from isotropic edge to isotropic edge). Consider the pessimistic situation where this typical RAO antenna is pointing at a low elevation of 10° from the horizon. Assuming a slow aircraft (185 mph) flying at 20,000 feet directly toward the ground RAO antenna, approximately 7 minutes would elapse while the aircraft was within the 8° beamwidth. The signal-coupling condition would be mainbeam-to-mainbeam during part of this time interval. Fortunately, however, the occurrence of this situation is likely to be very infrequent. The interference level would be just 5.8% of a typical object-tracking integration time of two hours, and only 21% of 2000 seconds.

While the second interference condition (the side or backlobe of the aircraft antenna pattern couples into the mainlobe of the RAO antenna pattern, or vice-versa) may occur more often than the first condition, its probability of occurrence is still extremely small. Also, assuming the same beamwidth and elevation-angle conditions, less time is involved in crossing the beamwidth of the RAO antenna.

Aircraft runways that point directly at an RAO, and are located within radio-line-of-sight, provide (as a minimum) an A/G DME mainbeam-to-RAO sidelobe interference condition possibility every time an aircraft landing takes place on that runway. Thus, should the MLS DME, operating in the C-Band, be installed at airports whose runway azimuths point toward an RAO, a case-by-case analysis to consider the parameters of the particular RAO station may be necessary.

A sidelobe-to-sidelobe coupling condition has a high probability of occurring at all RAO's analyzed, and was considered as the normal interference condition on which this analysis is based. The airborne antenna was assumed to have a gain of 0 dBi in this condition.

TOTAL REQUIRED COUPLING LOSS

The quantity $S_H B$ (in dBm/m^2), as defined in Reference 2 was renamed Power Density, P_d, for the remainder of this report. The value of -141 dBm/m^2 was the power density threshold criterion used in determining a required total effective coupling loss between the airborne DME transmitter and representative RAO station receivers. The required coupling loss combines off-frequency rejection, propagation loss, and diffraction loss.

In order to arrive at the formula for the required total coupling loss, the following two equations are combined:

$$P_r = P_t + G_t + G_r - \text{Required Loss} \tag{3}$$

and

$$P_d = P_r - G_r + 20 \log f - 38.6 \tag{4}$$

where

P_r = power into the receiver, dBm

P_t = transmitter power, dBm

G_t = transmitter antenna gain in direction of receiver, dBi

G_r = receiver antenna gain in direction of transmitter, dBi

P_d = power density at the receiver antenna, dBm/m^2

f = transmitter operating frequency, MHz.

Equation 3 can be rewritten as:

$$\text{Required Loss} = P_t + G_t - (P_r - G_r) \qquad (3A)$$

Solving Equation 4 for the quantity $(P_r - G_r)$ and substituting into Equation 3A results in the required loss equation used in this analysis:

$$\text{Required Loss} = P_t + G_t - P_d + 20 \log f - 38.6 \qquad (5)$$

where all terms have been defined.

Thus, for the CCIR criterion of -141 dBm/m^2 and average MLS DME transmitter power,

$$\text{Required Loss} = 11 \text{ dBm} + 0 - (-141) + 74 - 38.6 = 187.4 \text{ dB}.$$

FREQUENCY-DEPENDENT REJECTION AND FREQUENCY-DISTANCE CURVES

Frequency-Dependent Rejection

The option 1 and option 6 FDR curves in APPENDIX A (Figures A-1 through A-8) depict the amount the MLS DME interfering signal is attenuated as a function of off-tuning from the tuned frequency of the RAO receiver. Essentially, the receiver selectivity is convolved with the transmitter's emission spectrum to derive an FDR curve. An ECAC computer program calculates FDR and frequency distance criteria when a transmitter emission spectrum and receiver selectivity are provided as point sets, usually given in dB units. FDR then is defined[7] as

$$\begin{aligned} \text{FDR} = {} & 10 \log \int 10^{[P(f) - G(f+\Delta f)]/10} df \\ & -10 \log \int 10^{[P(f) - G(f)]/10} df, \text{dB} \end{aligned} \qquad (6)$$

where

$P(f)$ = normalized input emission spectrum, in dB

$G(f)$ = normalized input selectivity curve, in dB

$G(f+\Delta f)$ = the translated (off-tuned) selectivity curve, in dB.

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[7]Fleck, R., *Procedures for Computing Separation Criteria and Off Frequency Rejection in Electromagnetic Compatibility Problems*, ESD-TR-67-5, ECAC, Annapolis, MD, March 1967.

The two integrals in the FDR equation are evaluated numerically by the trapezoidal method.

Frequency-Distance Curves

If it is required to maintain some total loss between a receiver and transmitter greater than that provided by the detuning associated with the frequency plan, the FDR calculated as above can be used to determine the remaining loss that must be made up by distance separation between the transmitter and receiver antennas. Figure 5 shows the general relationship between distance and propagation loss.

By combining FDR with transmitter power and antenna gain, and with receiving antenna gain, the required loss minus FDR can be converted to a required distance separation based on a smooth, 4/3-earth profile. This was done for each Δf (difference between transmitter frequency and receiver frequency) over the DME A/G transmitter tuning range. The result is a curve defining the relationship between Δf and the separation distance required to maintain the specified required loss.

In this analysis, the DME A/G transmitter emission spectrum illustrated in Figure 4 was used, together with four typical RAO receiver bandwidths, to generate FDR and F-D curves for both option 1 and option 6. The representative bandwidths selected to cover the range of RAO receiver bandwidths in TABLE 1 were 250 MHz, 50 MHz, 30 MHz, and 10 MHz. All selectivity curves have a selectivity floor of 60 dB with a falloff of 40 dB/decade, with the exception of the 50-MHz curve (typical of the VLA receiving system) which falls off at 80 dB/decade. In generating the FDR curves, the upper 3-dB selectivity point was placed at the upper edge of the radio astronomy band (5 GHz). This was necessary because most of the RAO receiver bandwidths encountered were broader than the allocated radio astronomy band, and this analysis does not consider interference to RAO receivers whose 3-dB band edge is at a frequency higher than the upper radio astronomy band edge.

In generating the F-D curves, seven total-loss values were used: 215, 210, 205, 200, 195, 190 and 185 dB. With the radio astronomy band limits fixed and the DME antenna sidelobe level assumed to be 0 dBm, Equation 5 becomes:

$$\text{Required Loss} = P_t - (P_d) + 35.4, \text{ dB}$$

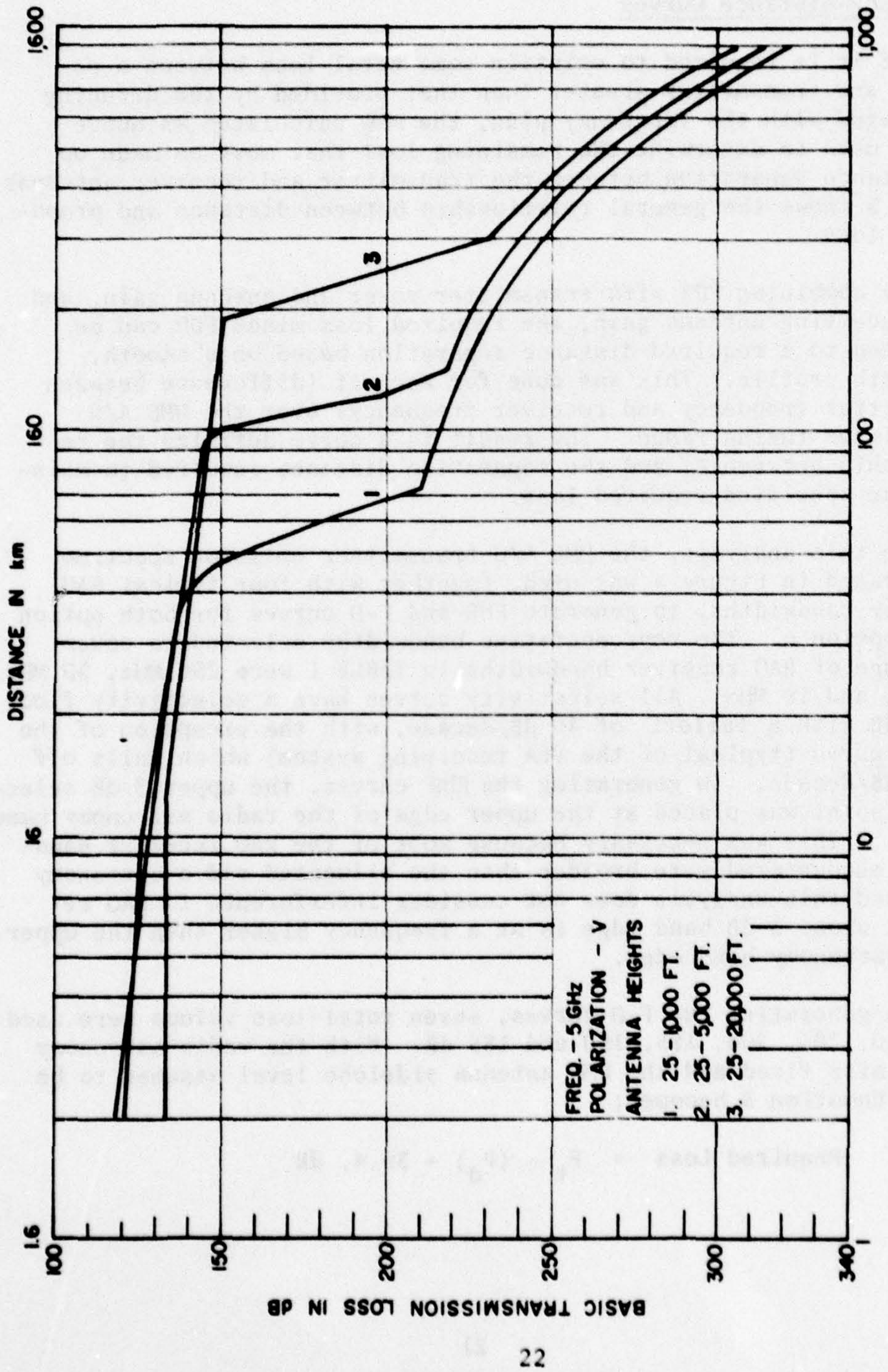

Figure 5. General relationship between distance and propagation loss for various transmitter antenna heights.

Thus, changes in either the power transmitted or the power density criterion, or both, will change the required loss value. TABLES 4 and 5 show the effect of changing one independent variable while keeping the other constant for the seven different required loss values used in the F-D curves in this report. In the left-hand column of TABLE 4, values of transmitter power corresponding to the indicated required loss values are given, power density having been held constant at -141 dBm/m^2. In the left-hand column of TABLE 5, calculated power density values for each required loss value are provided, assuming a constant average transmitter power of 11 dBm.

TABLE 4

TRANSMITTER POWER VERSUS REQUIRED LOSS FOR CONSTANT POWER DENSITY

Transmitter Power, P_t (dBm)[a]	Required Loss (dB)
8.6	185
11.0	187.4
13.6	190
18.6	195
23.6	200
28.6	205
33.6	210
38.6	215

[a] P_d = -141 dBm/m^2.

TABLE 5

POWER DENSITY VERSUS REQUIRED LOSS FOR CONSTANT TRANSMITTER POWER

Power Density, P_d (dBm/m^2)[a]	Required Loss (dB)
-138.6	185
-141.0	187.4
-143.6	190
-148.6	195
-153.6	200
-158.6	205
-163.6	210
-168.6	215

[a] P_t = 11 dBm.

The required loss value that corresponds to the CCIR criterion of -141 dBm/m^2 and the MLS DME average power of 11 dBm is also included in TABLES 4 and 5 (-187.4 dB). The table permits a degree of flexibility if it is desirable to use some other criterion. For example, if a power density criterion of -136 dBm/m^2 is selected and the effective DME transmitter power is assumed to be 16 dBm, these values would also result in a required loss value of -187.4 dB.

The F-D curves in APPENDIX A are all for a fixed power denisty of -141 dBm/m^2 (the CCIR criterion).

Figures 6 through 13 are frequency vs. distance curves for options 1 and 6 as a function of DME effective average power level for the four receiver bandwidths. In each figure, curves for the seven selected required loss cases (values in parentheses) are provided, and the corresponding DME average power level is given for each curve. The abscissas of the F-D curves are in units of frequency difference (Δf) between the airborne DME transmitter frequency and the RAO receiver frequency. Thus, for a receiver with a 10-MHz bandwidth whose upper 3-dB point is at 5000 MHz and a DME transmitter whose output frequency is 5128 MHz (see Figure 12), Δf would be the difference between 5128 MHz (option 6) and 4995 MHz, or 133 MHz. This point would correspond to the left-most point on the F-D curve. At the other end of the DME transmitter range, Δf = 5187.7 - 4995 = 192.7 MHz. This is the maximum abscissa value of the Δf curve. The ordinate is in units of nautical miles and kilometers.

In using the curves, a vertical line is constructed from the Δf of interest to intersect the F-D curve. From this intersection, a horizontal line to the left is constructed and the distance required to maintain the total loss requirement is read on the ordinate scale.

An examination of Figures 6 and 7 indicates that, for the 250 MHz receiver bandwidth (typical of NRAO, Greenbank, WV), neither option 1 nor option 6 permits a separation distance smaller than 160 nmi for any combination of frequency separation and DME transmitter power. In other cases, however, option 6 permits smaller separation distances than does option 1.

For the VLA receiver at Socorro, NM (50 MHz receiver bandwidth, Figures 8 and 9), a single airborne DME transmitter (11 dBm) using option 1 requires a distance separation of at least 175 nmi for frequency separations of 65 MHz or less, whereas option 6 requires only a 12 nmi distance separation.

Figures 10 and 11 indicate that, for the RAO receivers with 30 MHz bandwidth (typical of the majority of RAO's) option 1 requires a 175 nmi separation for a single DME transmitter (11 dBm), whereas option 6 requires only 90 nmi.

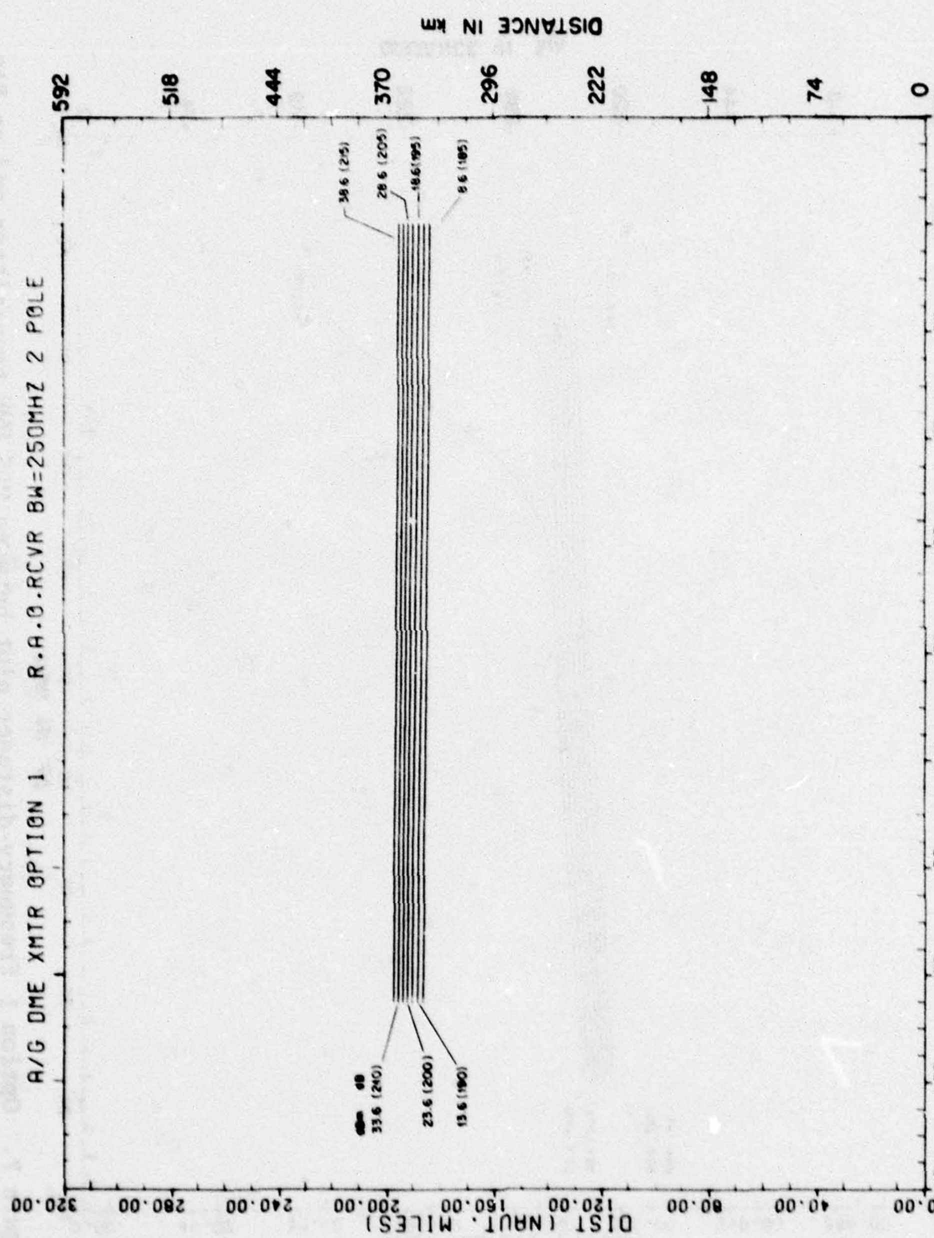

Figure 6. Option 1 frequency-distance plot between MLS DME and an RAO receiver with a 250-MHz bandwidth.

Figure 7. Option 1 frequency-distance plot between MLS DME transmitter and an RAO receiver with a 50-MHz bandwidth.

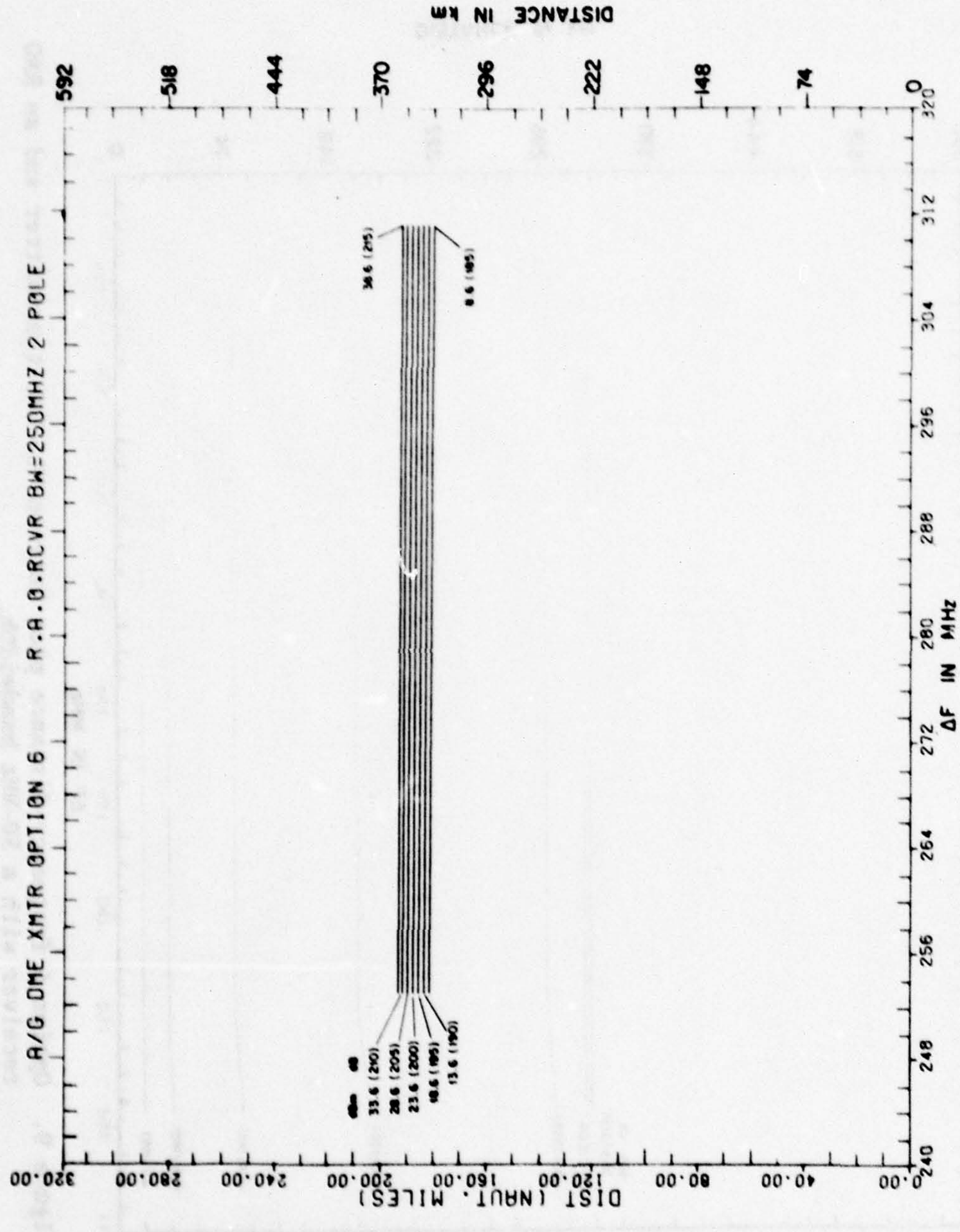

Figure 8. Option 6 frequency-distance plot between MLS DME transmitter and an RAO receiver with a 250-MHz bandwidth.

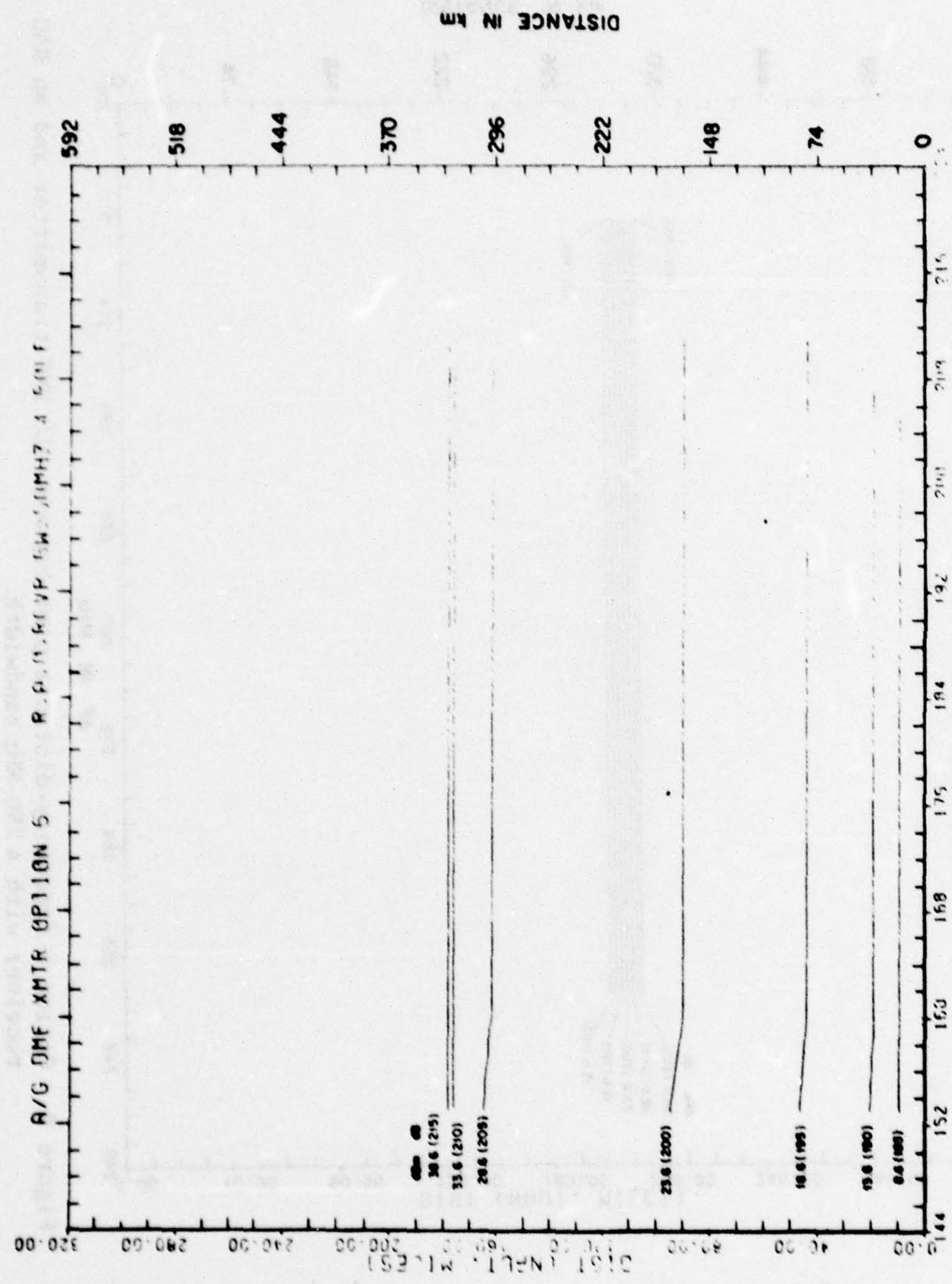

Figure 9. Option 6 frequency-distance plot between MLS DME transmitter and an RAO receiver with a 50-MHz bandwidth.

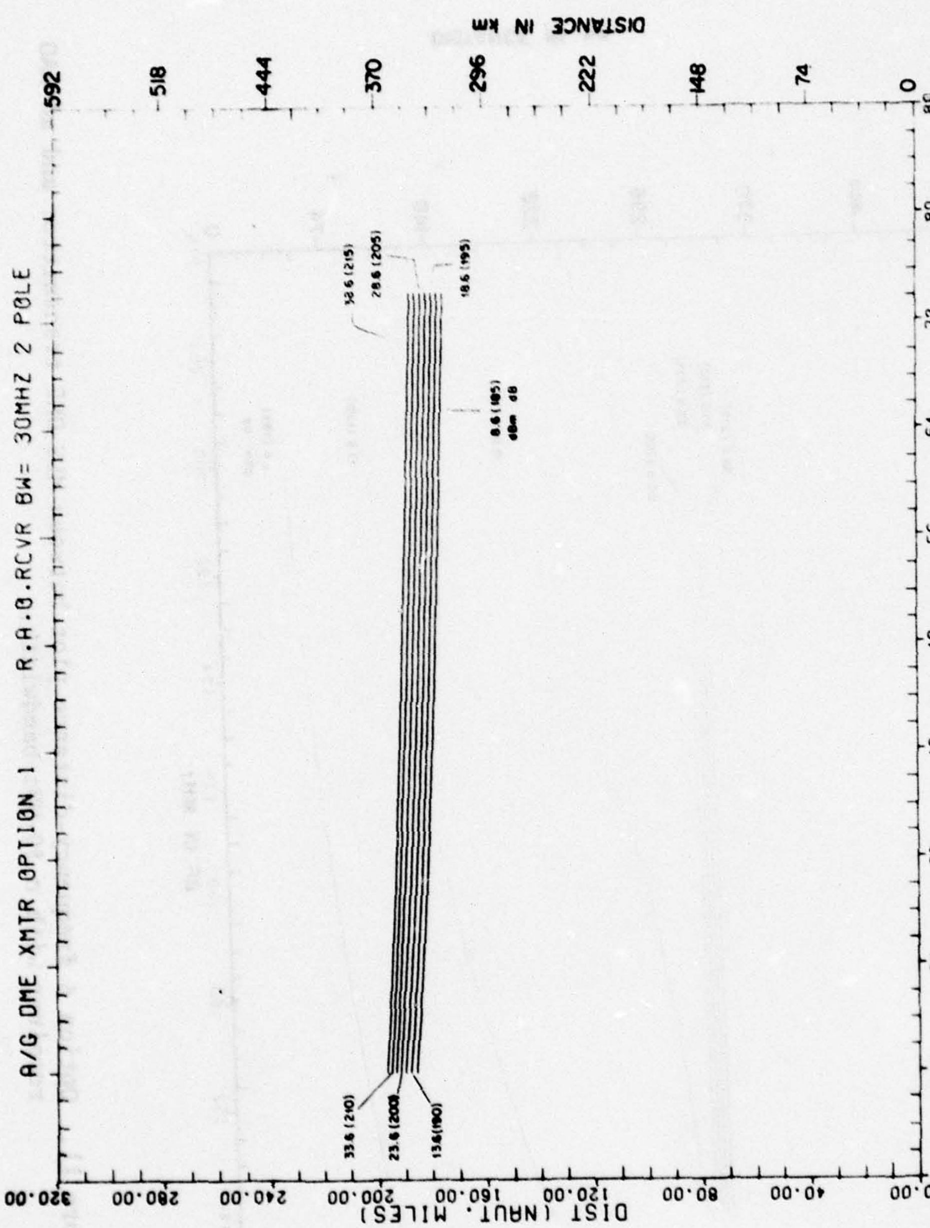

Figure 10. Option 1 frequency-distance plot between MLS DME transmitter and an RAO receiver with a 30-MHz bandwidth.

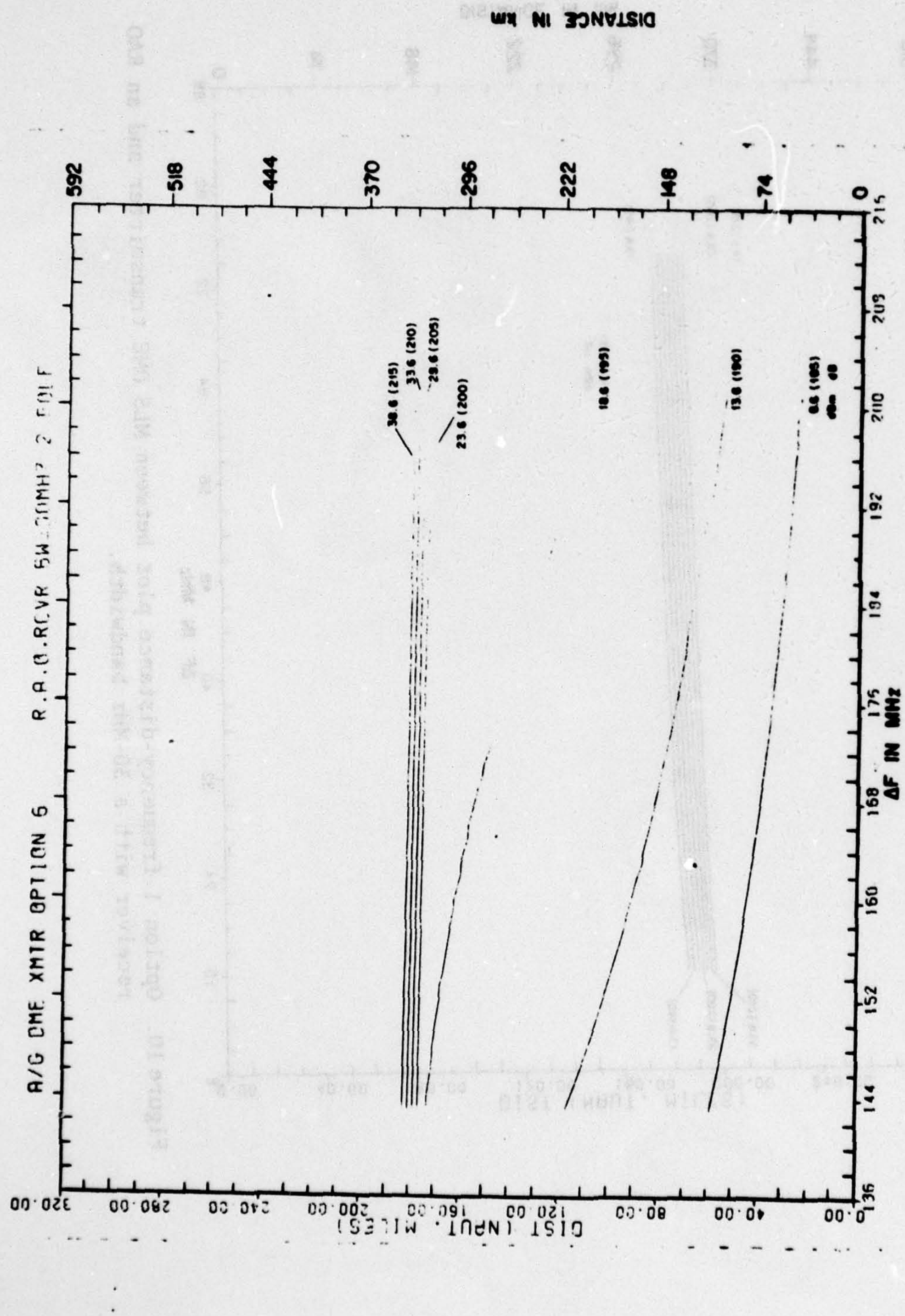

Figure 11. Option 6 frequency-distance plot between MLS DME transmitter and an RAO receiver with a 30-MHz bandwidth.

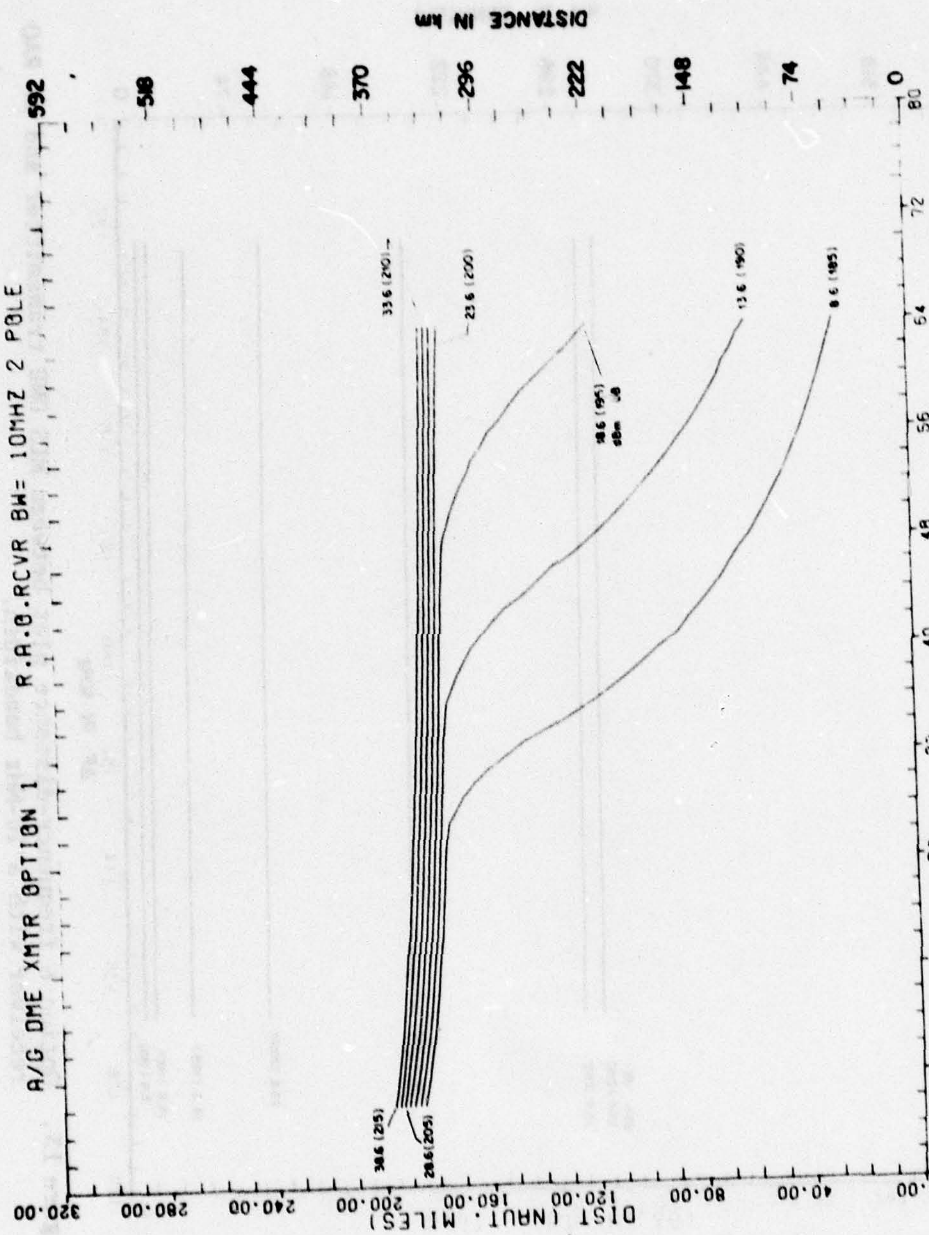

Figure 12. Option 1 frequency-distance plot between MLS DME transmitter and an RAO receiver with a 10-MHz bandwidth.

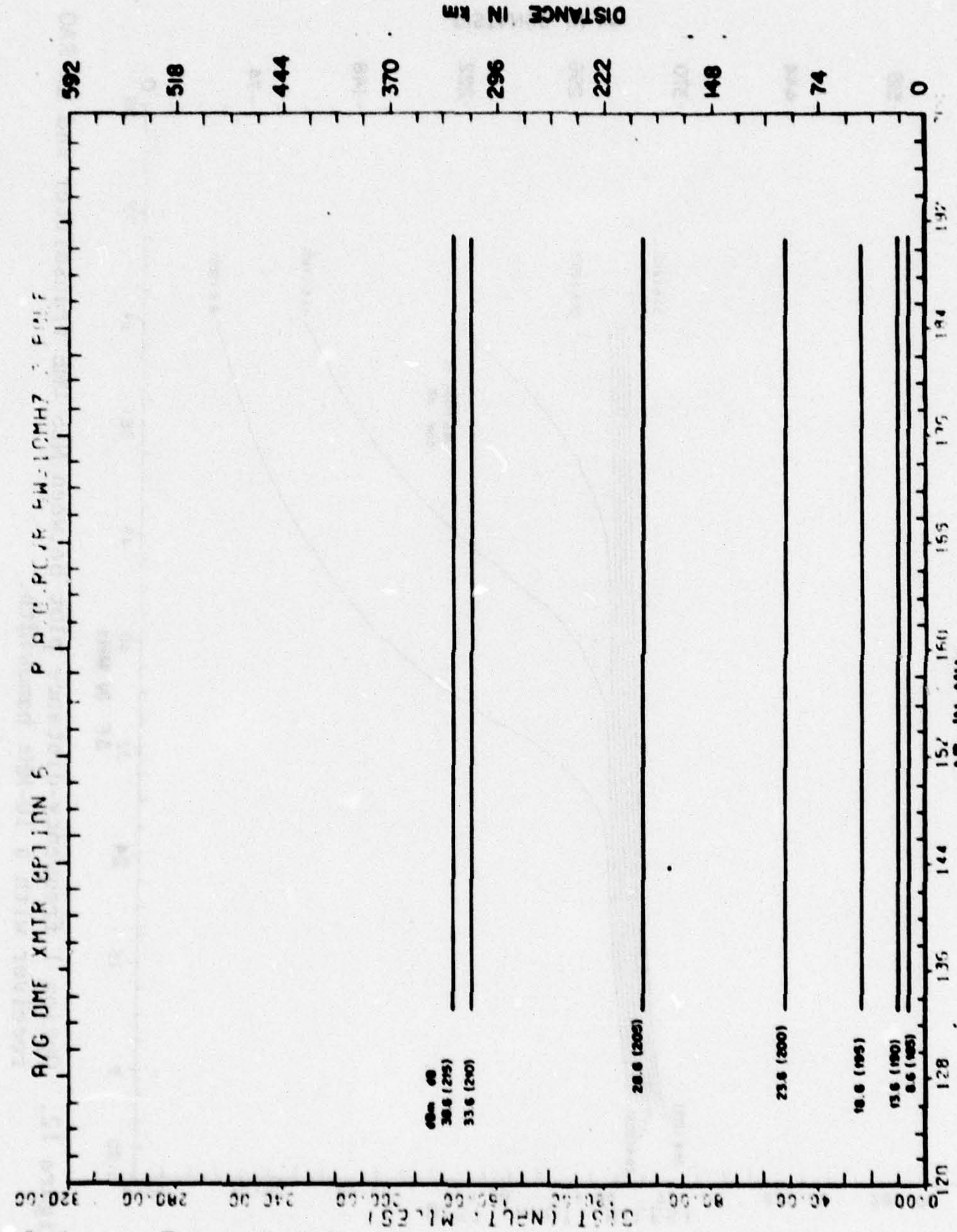

Figure 13. Option 6 frequency-distance plot between MLS DME transmitter and an RAO receiver with a 10-MHz bandwidth.

Figures 12 and 13 show that, for the 10 MHz receiver bandwidth, option 1 requires a minimum separation of 175 nmi for a power of 11 dBm and frequency separations less than 25.5 MHz. However, option 6 requires a separation distance of only 8.5 nmi for a power of 11 dBm.

The simplest case, and the one with the least effect, is represented by the presence of one DME-equipped aircraft (average power 11 dBm) and one ground transponder in the vicinity of one RAO receiver. However, a more realistic operating condition would include more than one aircraft making landing preparations within 20 nmi of an airport. Each aircraft using the MLS DME system within radio line of sight of an RAO receiver would contribute to the overall effective average power being received.

TABLE 6 indicates the cumulative effect of several aircraft operating simultaneously. The effective transmitter power jumps from 11 dBm with one DME-equipped aircraft to 18 dBm with five. With 20 operating aircraft in the area (a reasonable traffic load near busy airports), the effective transmitter power becomes 24 dBm. The basis for this table is, that by adding more aircraft, the effective pulse rate of the interfering signal increases. For example, the minimum pulse rate from one DME-equipped aircraft is 30 pulse-pairs per second, or 60 pps. For 2 aircraft, the interfering signal pulse rate is equivalent to 120 pps; for 3 aircraft, it is 180 pps, etc. This then effectively increases the average power in the following manner:

$$\bar{P} = \hat{P} + 10 \log(dc) \tag{7}$$

where

$\bar{P}$ = average transmitted power (dBm)

$\hat{P}$ = peak transmitted power (dBm)

dc = duty cycle

= (pulse width) x (effective pulse rate).

These increases in effective power, resulting from multiple aircraft operating simultaneously, have a significant effect on distance separation requirements. For example, the separation requirement for a single aircraft transmitting on the lower DME frequency of option 6 is 12 nmi from an RAO receiver with a 50 MHz bandwidth, whereas the required separation for 20 aircraft operating simultaneously is approximately 85 nmi. Similarly, for the 30 MHz receiver bandwidth under the same conditions, the separation requirement jumps from 90 nmi to 170 nmi; for a 10 MHz bandwidth the increase is from 9 nmi to 52 nmi.

TABLE 6

EFFECTIVE POWER AS A FUNCTION OF TRAFFIC DENSITY

Number of Aircraft	Resulting Effective Average Power (dBm)
1	11
5	18
10	21
15	22
20	24
25	25
30	25.8
35	26.4
40	27.0

Because of the large separation distances indicated by some of the F-D curves, especially those for a bandwidth of 250 MHz, an investigation was made of the possibility of modifying the airborne DME transmitter spectrum (Figure 4) by adding a high-pass filter, which would steepen the left slope beyond the -70 dB point to a fall-off rate of 100 dB/decade. Figure 14 shows the lower frequency end of the airborne DME transmitter spectrum with the center frequency located at 5128 MHz (the first DME A/G channel in the option 6 channel plan), and the upper half of the RA receiver selectivity curves. For this plot, each RAO receiver was tuned such that its upper 3 dB point fell exactly at 5,000 MHz. This was done so that it appears, relative to the MLS frequency band, that the RAO receivers are never tuned beyond the upper end of this band (this, of course, may not be true). The dashed line shows the DME transmitter spectrum with the center frequency shifted up 30 MHz to 5158 MHz.

Even though the ordinate is plotted in relative dB, the conditions contributing to potential interference are seen to be the wide bandwidths and shallow fall-off slopes of the RA receivers. This was substantiated by recomputing (for option 6 and option 6 shifted 30 MHz) the FDR and F-D curves for the same power density threshold values, but reshaping the slope of the airborne DME transmitter spectrum beyond the -70 dB point to 100 dB/decade to reduce the transmitter's energy at and beyond the 5,000-MHz RA band edge. There was no significant change in FDR or F-D curves in either case, as compared with the original FDR and F-D curves.

One moderating factor is that observatories, on occasion, may use filters which provide a slope fall-off sharper than the 40 dB/decade chosen for the RAO receivers of this analysis. However, conversations with RAO personnel indicate that there is a reluctance on their part to add an insertion loss which, aside from the cost, could detract from the sensitivity of their measurements.

TERRAIN EFFECTS

The frequency-distance curves of Figures 6 through 13 were computed using a smooth-curve, smooth-earth model that does not account for terrain shielding. Several of the listed RAO sites were examined to determine how large a radio shielding area could be expected from the local terrain features surrounding the sites. Average land conditions were used to compute the radio line-of-sight from each RAO to an aircraft at 20,000 feet above sea level. The locus of these radio line-of-sight points form a 20,000-foot acquisition contour as shown in Figures 15 through 19. The 20,000-foot acquisition contour lines shown on the figures define limits of the radio line-of-sight region from the particular RAO station site.

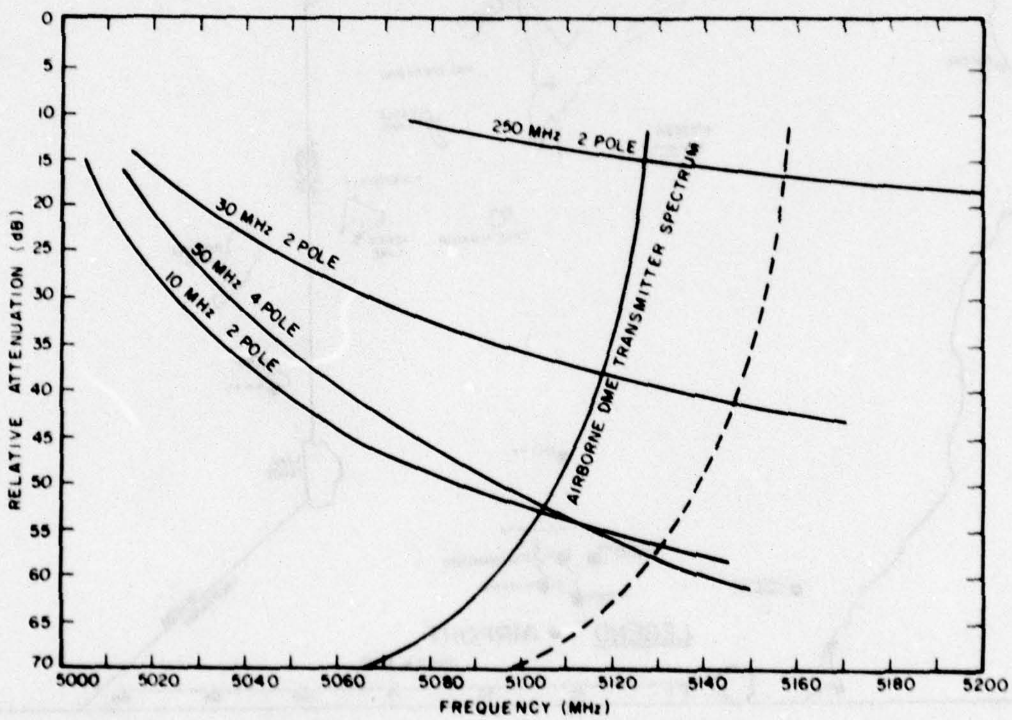

Figure 14. Environmental equipment frequency characteristic curves.

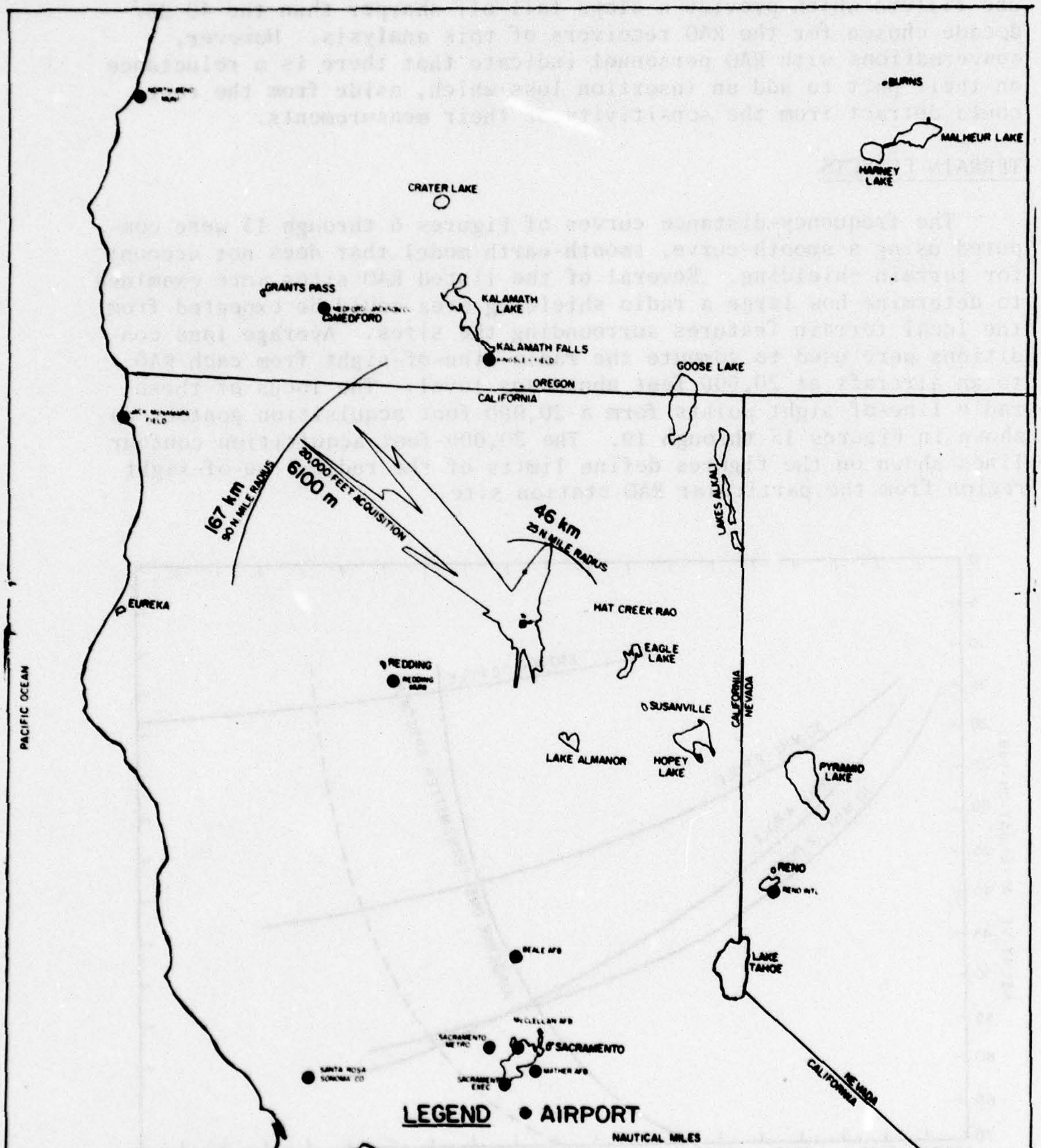

Figure 15. 20,000 foot (6100 m) radio line-of-sight acquisition contour centered at Hat Creek RAO Calif.

Figure 16. 20,000 foot (6100 m) radio line-of-sight acquisition contour centered at Owens Valley RAO Calif.

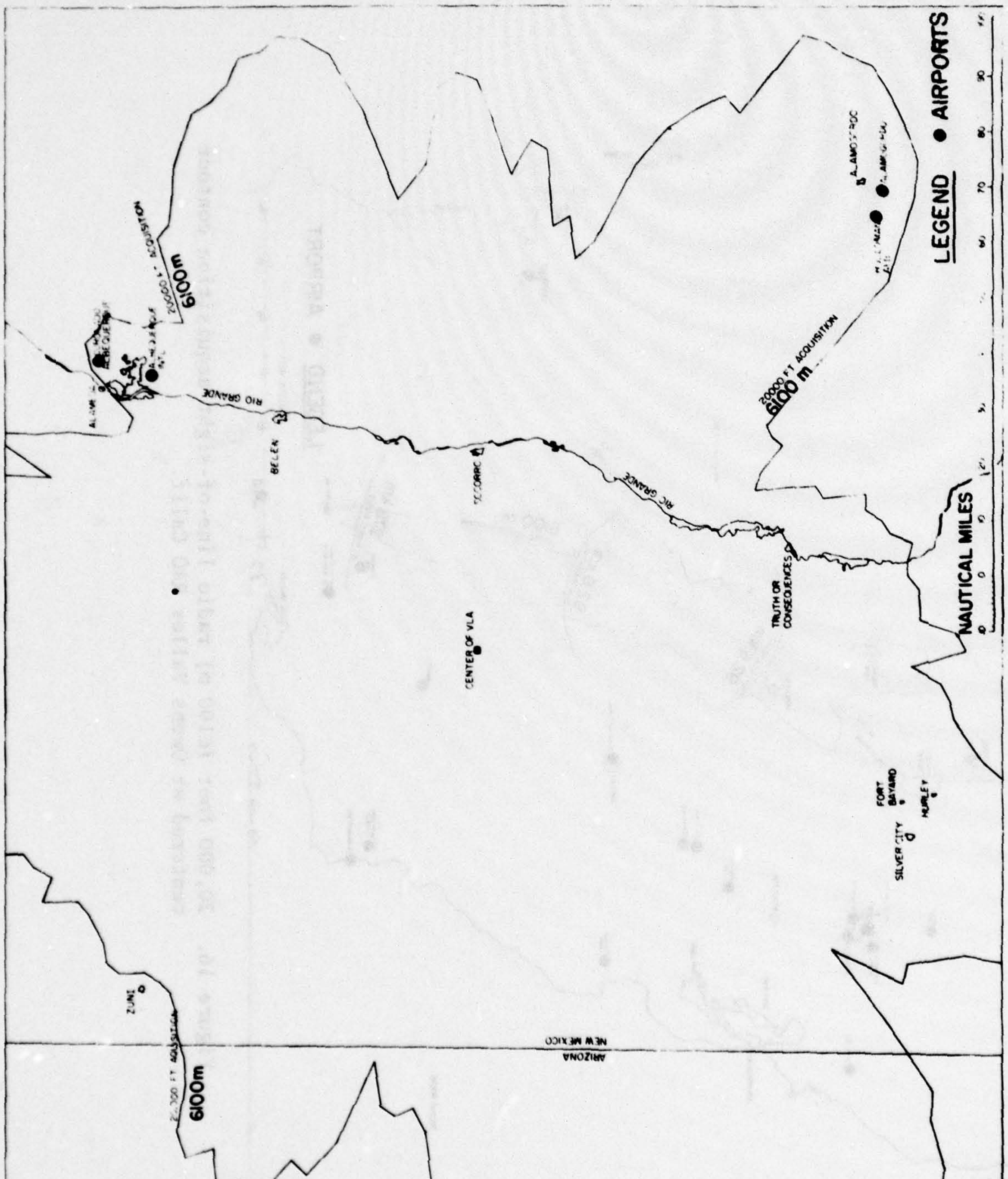

Figure 17. 20,000 foot (6100 m) radio line-of-sight acquisition contour centered at Very Large Array (VLA) RAO N.M.

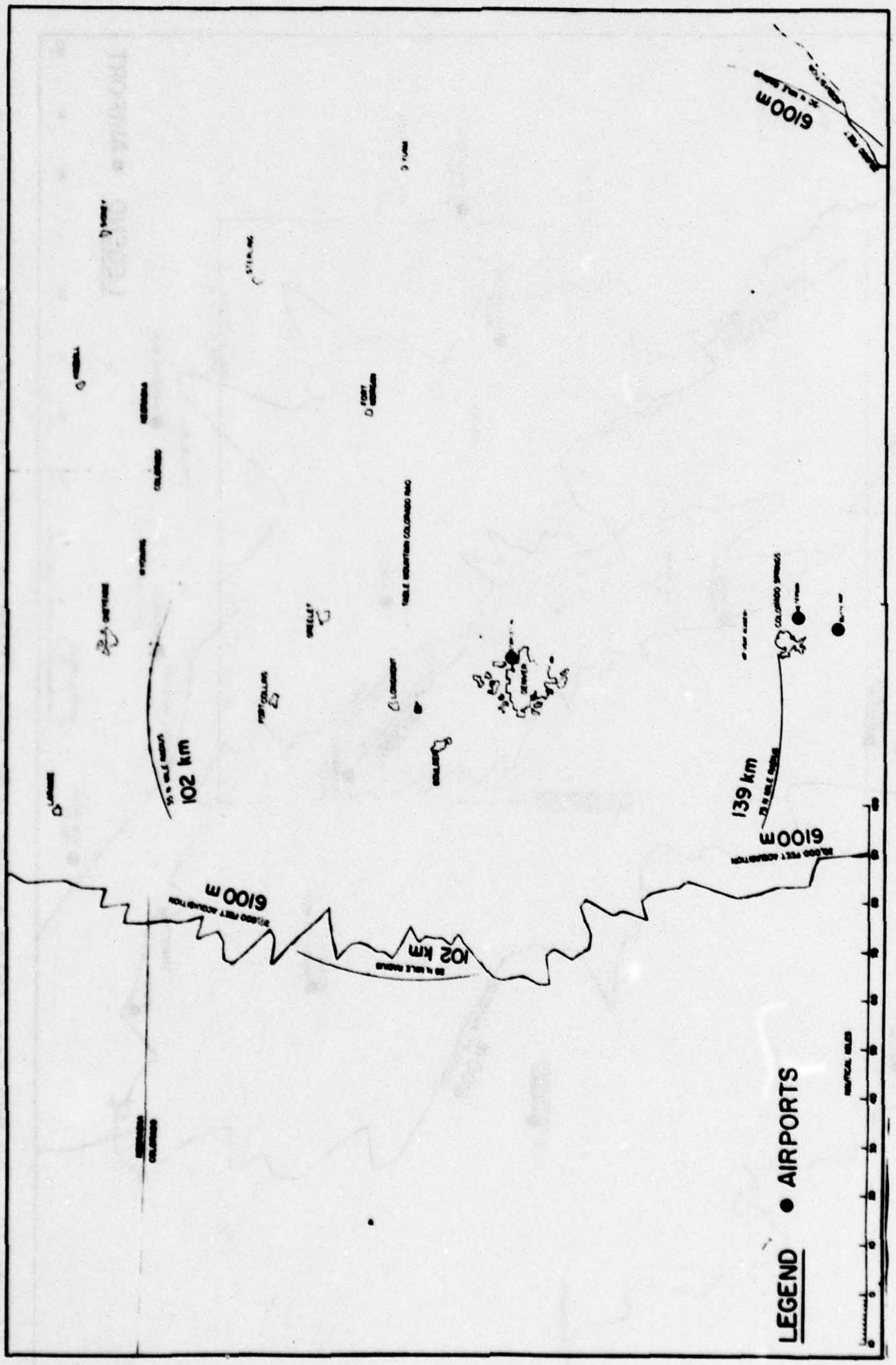

Figure 18. 20,000 foot (6100 m) radio line-of-sight acquisition contour centered at Table Mountain RAO Colo.

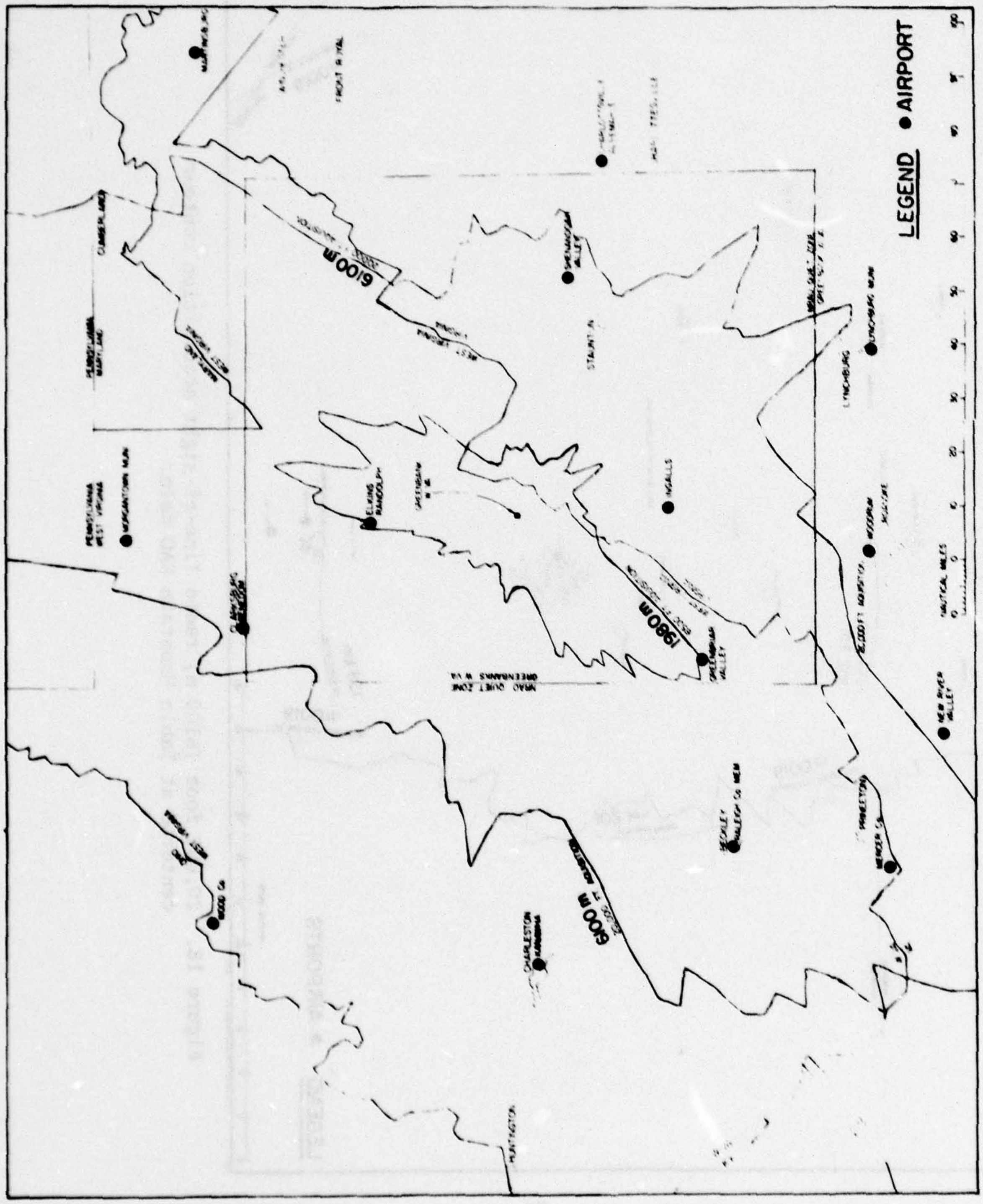

Figure 19. 20,000 foot (6100 m) and 6500 foot (1980 m) radio line-of-sight acquisition contours centered at Greenbank, W. VA.

Figure 20 shows the three RAO stations in Massachusetts. Radio line-of-sight regions were defined for each station, but since they were close in proximity, only one contour is represented on the map. For the purposes of this discussion, it can represent all three sites. Also, the geographic center among the three was considered to be the site location and all radius lines are referred to that center location.

An aircraft flying at an altitude of 20,000 feet would be within radio line-of-sight of the RAO if it were inside the 20,000-foot acquisition contour, in which case the F-D curves could help determine whether some desired power density threshold had been met. Outside of this 20,000-foot acquisition contour line, the total propagation loss between the aircraft and the RAO would increase, relative to smooth earth loss, because of diffraction effects due to terrain obstruction. As an example, at 5 GHz and at a distance of 25 miles beyond the radio line-of-sight contour, an additional 50 dB of attenuation could be added to the smooth-curve, smooth-earth loss.

Airports that are likely candidates for the MLS DME system are identified on each figure by the symbol ●. Those airports that already have operating Airport Surveillance Radars (ASR) and/or Instrument Landing Systems (ILS), as indicated in current flight information publications, were considered.

Figure 15 shows the site of the Hat Creek Radio Astronomy Observatory in California with 12 candidate airports, none of which are within the 20,000-foot acquisition contour. Redding Municipal, the airport closest to the radio line-of-sight contour, is approximately 35 miles outside the contour and roughly 45 miles from the RAO. An aircraft at 20,000 feet 20 miles from the airport in the direction of Hat Creek would still be at least 15 miles from the line-of-sight contour, but quantitative values of power density and propagation loss cannot be accurately assessed. The only possibility for interference to the Hat Creek RAO from A/G DME would come from air traffic near that airport. However, the runway's azimuth of 180° true eliminates the possibility of A/G DME main beam-to-RAO sidelobe coupling on landing approach. From an interference point of view, this RAO site is well protected by local terrain shielding.

Figure 16 shows the Owens Valley RAO with 19 surrounding candidate airports. The only possibilities for interference to this RAO receiver from the MLS A/G DME system would be from air traffic around George AFB or Edwards AFB. Aircraft in approach patterns near these airports are border-line potential interference sources.

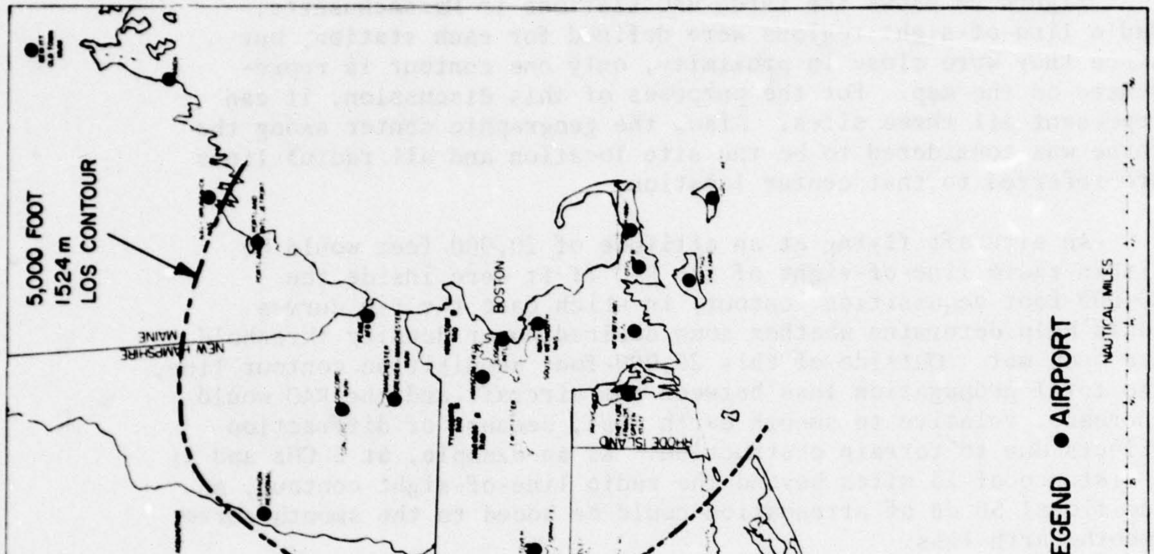

Figure 20. Map overlay of New England.

George AFB is just outside the 20,000 foot acquisition contour and approximately 165 miles from the RAO, with a runway azimuth of 005° true. This azimuth may afford an A/G DME main beam-to-RAO sidelobe coupling possibility on landing approach. Edwards AFB is outside the acquisition contour, 145 miles from the RAO, but an aircraft 20 miles east of this airport would be inside the acquisition contour. The Edwards AFB runway azimuth closest to the RAO is 057° true and landing-approach coupling is not likely to be a problem. However, both airports present the possibility of an RAO main beam-to-A/G DME sidelobe coupling when the RAO station is tracking a celestial object across the southern sky.

Figure 17 shows the area surrounding the NRAO VLA near Socorro, NM, and five surrounding airports. Four of the five are within the 20,000-foot acquisition contour with distances from the RAO ranging from approximately 75 to 110 miles. Alameda airport lies just outside the contour at a distance from the RAO of approximately 80 miles. An examination of the F-D curves in Figure 8 (corresponding to the option-6 channel plan for this RAO receiver) shows that 90 nmi would be the required separation distance for 20 DME-equipped aircraft, but that approximately 15 aircraft could operate compatibly at a distance of 80 nmi. This, of course, assumes that the VLA RAO is never tuned higher than 4975 MHz. However, both Alameda and Albequerque International airports have runways whose azimuths point reasonably close to the RAO station, thus offering possibilities for A/G DME main beam-to-RAO sidelobe coupling.

Figure 18 shows the Table Mountain RAO area near Boulder, CO, and three airports, all of which are within the 20,000-foot radio line-of-sight acquisition contour. The nearest airport (Stapleton), whose closest runway azimuth is 003° true, is approximately 22 miles away, while the farthest of the three (Butts) is roughly 88 miles from the RAO. The closest runway azimuth at Peterson airport is 360° true. The air traffic associated with all three airports could contribute to potential interference, depending on traffic density.

Figure 19 shows the area surrounding NRAO Greenbank, WV, including 15 candidate airports and the "quiet zone" area. Seven of the fifteen airports lie outside the 20,000-foot acquisition contour. However, an examination of Figure 6 (the F-D curves for the type of receivers at this RAO) shows that, because of the extreme bandwidths employed here, very large separation distances are required. Moreover, Lynchburg, Mercer County and Morgantown airports all have runway azimuths pointing toward the RAO site. In fact, of the 15 airports in the area, only Wood Co. Airport air traffic can be excluded as a possible interference source.

Figure 20 shows the area surrounding the RAO's in Massachusetts. The 180 nmi radius represented on the map is approximately the minimum separation distance required to maintain the CCIR criterion of -141 dBm/m^2, consistent with the bandwidths employed. This area is heavily congested, both in terms of RAO's and airports. Within 180 nmi of the RAO sites there are 38 airports, 21 of which are between the 180-mile radius and the average 5000-foot acquisition contour. Of the 17 airports within the 5000-foot acquisition contour, only four airports (Portland, Westover, Barns, and New Bedford) do not have runway azimuths which could contribute to an A/G DME main-beam-to-RAO sidelobe signal coupling situations. The closest two airports (Hanscom Field and Logan International) are within 25 miles of the three RAO sites. Even airport traffic in the state of New York could be a source of interference.

For example, given frequency-plan option 6, assume an MLS DME aircraft transmitting on 5152.5 MHz is flying at 20,000 feet on approach to Albany County Airport, whose runway azimuth is 087° true. Also, assume that Hamilton, MA, RAO is using a receiver with a 10 MHz bandwidth tuned to 4995 MHz and that the Tyngsboro, MA, RAO is using a 30-MHz bandwidth and is tuned to 4985 MHz. This tuning would place the upper 3-dB selectivity curves for both receivers at the upper limit of the Radio Astronomy Band. Then the Δf for Hamilton would be 5152.5-4995 MHz, or 157.5 MHz, and the Δf for Tyngsboro would be 167.5 MHz.

The appropriate F-D curve for Hamilton, MA, (Figure 13) shows that up to 40 aircraft could operate within 20 nmi of Albany Airport (110 nmi from Hamilton) without adverse effect. However, for the Tyngsboro, MA, case (Figure 11, 130 nmi from Albany) more than five aircraft could cause a problem. Thus, depending upon the DME operating frequency and the particular RAO receiver in operation, it would be possible for significant interference to occur to all of the three RAO stations in this area. This same situation is true of Warren County Airport and Peconic River Plan Airport, both approximately the same distance away as Albany County, and both having runway azimuths pointing toward the RAO sites.

Based upon the findings and interpretation of this analysis, only a few RAO's are adequately shielded by terrain; most of the RAO stations can receive significant signal levels from DME airborne transmissions when more than five DME equipped aircraft are operating within line-of-sight, especially in areas such as Massachusetts where there is little local terrain shielding and the 20,000-foot contours extend over a considerable area. If the MLS-A/G-DME is to operate in the 5.001-5.25 GHz band, and if the radio astronomy observatories operating within the 4.990-5.000 GHz band are to be

afforded adjacent-band interference protection as suggested in the CCIR 224-2 report, receiver selectivity filtering sharper than that assumed in this report is necessary.

At the time of installation of the MLS DME at any airport in the area of an RAO operating in the 4.99-5.00 GHz band, especially those indicated as having possible mainlobe-to-mainlobe or mainlobe-to-sidelobe antenna coupling conditions, coordination between the FAA and the particular RAO would be required to develop procedures for protecting the RAO from excessive adjacent-band interference.

RADIO ASTRONOMY BAND-EDGE INTERFERENCE CRITERION

With the RAO receiver bandwidths employed, the CCIR criterion of -141 dBm/m^2 would require unacceptably large separation distances when the RAO stations are not shielded by terrain and a number of aircraft are operating DME simultaneously. However, the latest recommendation of CCIR[8] suggests that adjacent-band emissions be limited to a suggested power density level at the band edge without regard to RAO receiver bandwidths. For the 5-GHz radio astronomy band, this limit is -141 dBm/m^2.

To reduce the adjacent-band interference from the A/G transmitter to a level of -141 dBm/m^2 at the upper band edge of 5000 MHz, thereby satisfying the CCIR criterion without regard to the receiver types or sensitivities employed in this band, an additional high-pass filter could be incorporated within the transmitter. Beginning with total loss, which has previously been calculated, the amount of additional filter attenuation necessary at 5.00 GHz can be computed as follows:

$$\text{Total Loss} - \text{FDR} + \text{FSL} + A = 231.4 \text{ dB}$$

A = 0 because line-of-sight distances are involved. Rearranging terms,

$$231.4 = \text{FDR} + 36.6 + 20 \log (5000 \text{ MHz}) + 20 \log (\text{dist.})$$

Assuming a distance of 20,000 ft. or 3.7878 statute miles,

$$231.4 = \text{FDR} + 36.6 + 74 + 11.6$$

[8]Documents of the XIII Plenary Assembly Volume XIII, Geneva 1974, International Radio Consultative Committee, ITU 1974, *Sensitivities of Radio Astronomy Receivers to Signals in Adjacent Bands*.

Assuming the A/G DME transmitter noise floor is 71 dB down,

$$FDR = 109.2 - 80 = 38.2 \text{ dB}$$

However, if one-mile separation distance is required, rather than 20,000 feet, 11.6 dB additional attenuation will be required or

$$FDR = 29.2 + 11.6 = 49.8 \text{ dB}$$

Thus, depending upon the separation distance requirements and the maximum allowable deterioration of the DME pulse risetime, a high-pass filter with the necessary attenuation characteristics at 5.00 GHz could be added to the airborne transmitter. If the CCIR criterion is met at the upper band edges, any adjacent-band signal seen by the RAO, within their 4990-5000 MHz band, from the A/G DME transmitter (interrogator) could be reduced to acceptable levels by filtering the RAO receiver system, as recommended in Reference 8.

SECTION 3

RESULTS

CONCLUSIONS

1. No adjacent-band interference protection criterion for radio astronomy bands has been stipulated by the Office of Telecommunications Policy. If the criterion suggested by CCIR Report 224-2 is adopted (-141 dBm/m^2 for the 5-GHz band), none of the proposed frequency plans for the MLS DME will provide this protection for RAO receivers in a multi-aircraft environment without resulting in unacceptably large separation distances or the need for filters. Considering the 158 MHz frequency separation afforded by the shifted option 6, this gives some indication of how severe the CCIR recommendations are.

2. Adding a high-pass filter with an attenuation characteristic of approximately 40 dB at 5 GHz would reduce the adjacent-band power density from the MLS DME transmitter (sidelobe-to-sidelobe coupling, smooth-earth propagation conditions) to -141 dBm/m^2 at the upper edge of the RAO band. Since this would impact the cost of the DME interrogator, it is questionable whether the FAA could mandate this course of action.

3. The RAO receivers generally have broad selectivity bandwidths and shallow slope fall-offs. Reduction of unwanted signals can be achieved by filtering in the RAO receivers to provide sharper selectivity skirts, as suggested in CCIR Report 547.

4. Only a few of the 10 RAO sites operating in and near the 4.990-5.000 GHz band in the U.S. are protected sufficiently by terrain shielding to prevent adjacent-band interference from the MLS DME airborne transmitter (based on the CCIR criterion of -141 dBm/m^2). In at least two geographic areas, mainbeam-to-mainbeam or mainbeam-to-sidelobe coupling could occur. In these cases, interference analyses on a case-by-case basis may be necessary.

5. The most congested area examined is in Massachusetts where there are 13 airports within the 20,000-foot (6100 m) radio line-of-sight contours around three RAO sites, and all have runway azimuths that point toward the sites. Another difficult area is near Greenbank, West Virginia, the NRAO site with the most sensitive receivers and the widest bandwidths. In this area, three airports within the 20,000-foot (6100 m) line-of-sight contour have runway azimuths that point toward the NRAO site.

6. **With regard to frequency planning for the MLS DME air-to-ground operation, the option 6 plan translated up 30 MHz would result in the least potential interference to RAO's, as compared with options 1 and 6.**

APPENDIX A

OPTION 1 AND OPTION 6 FREQUENCY-DEPENDENT REJECTION CURVES FOR FIVE REPRESENTATIVE RAO RECEIVERS

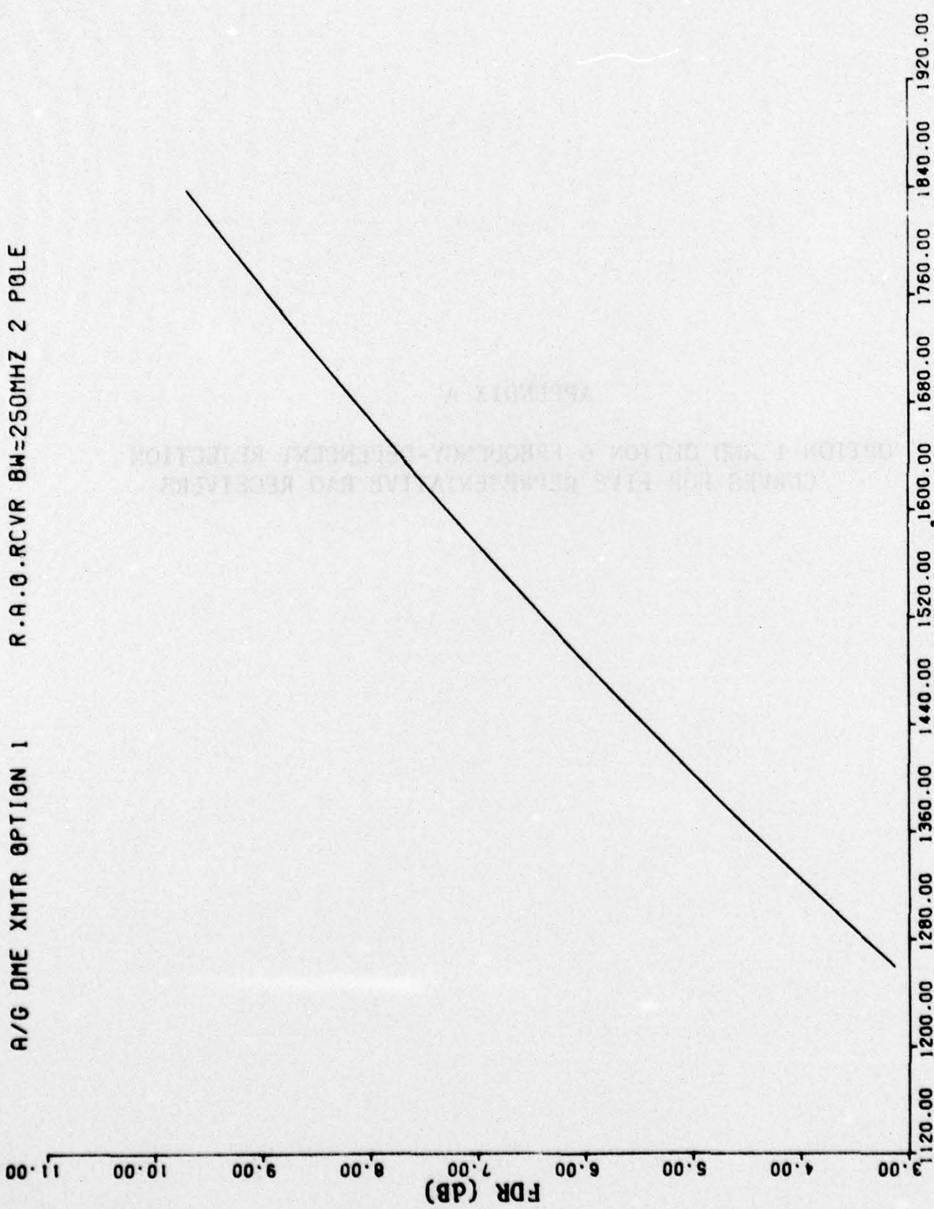

Figure A-1. FDR plot of option 1 with 250-MHz BW, 2-pole filter.

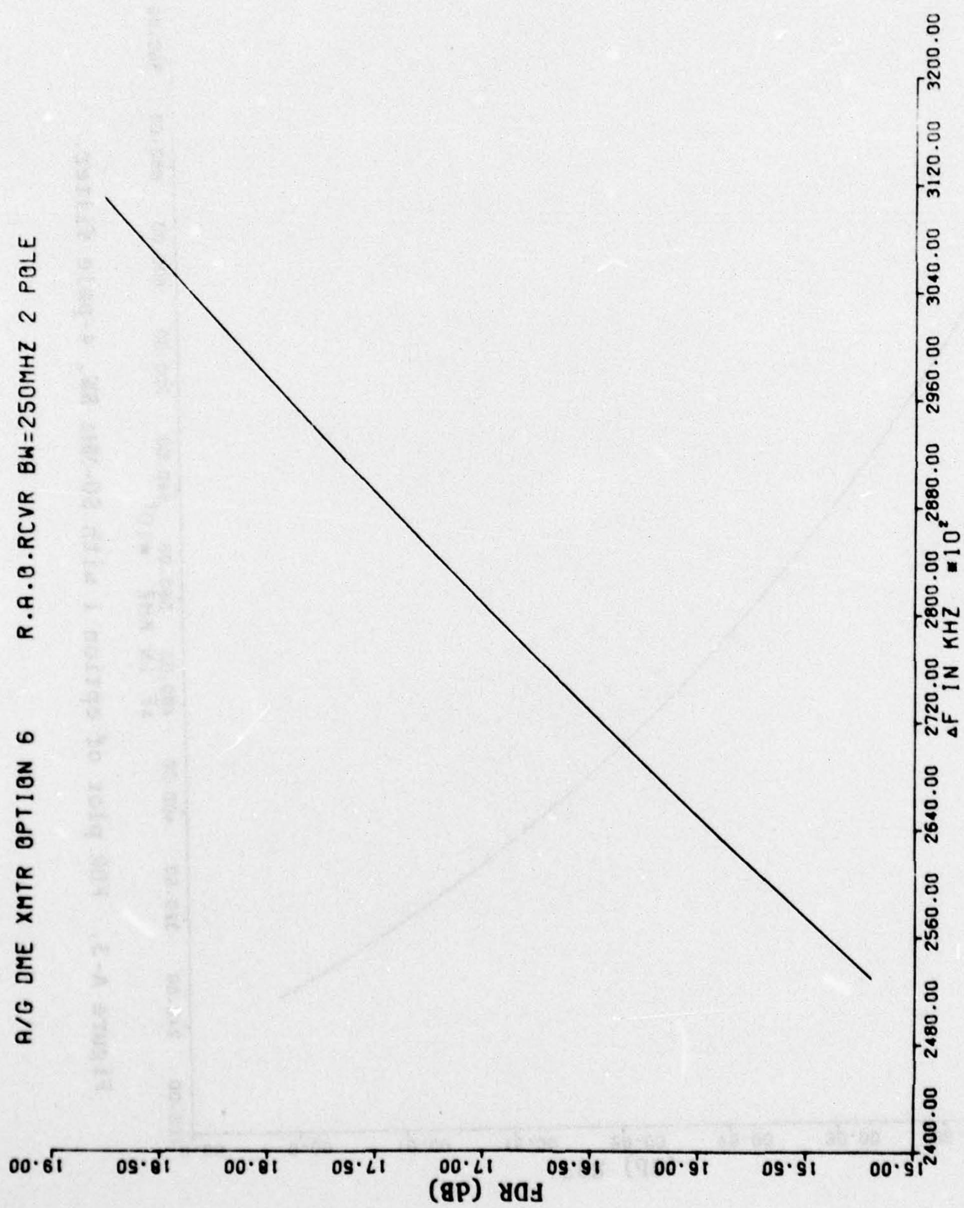

Figure A-2. FDR plot of option 6 with 250-MHz BW, 2-pole filter.

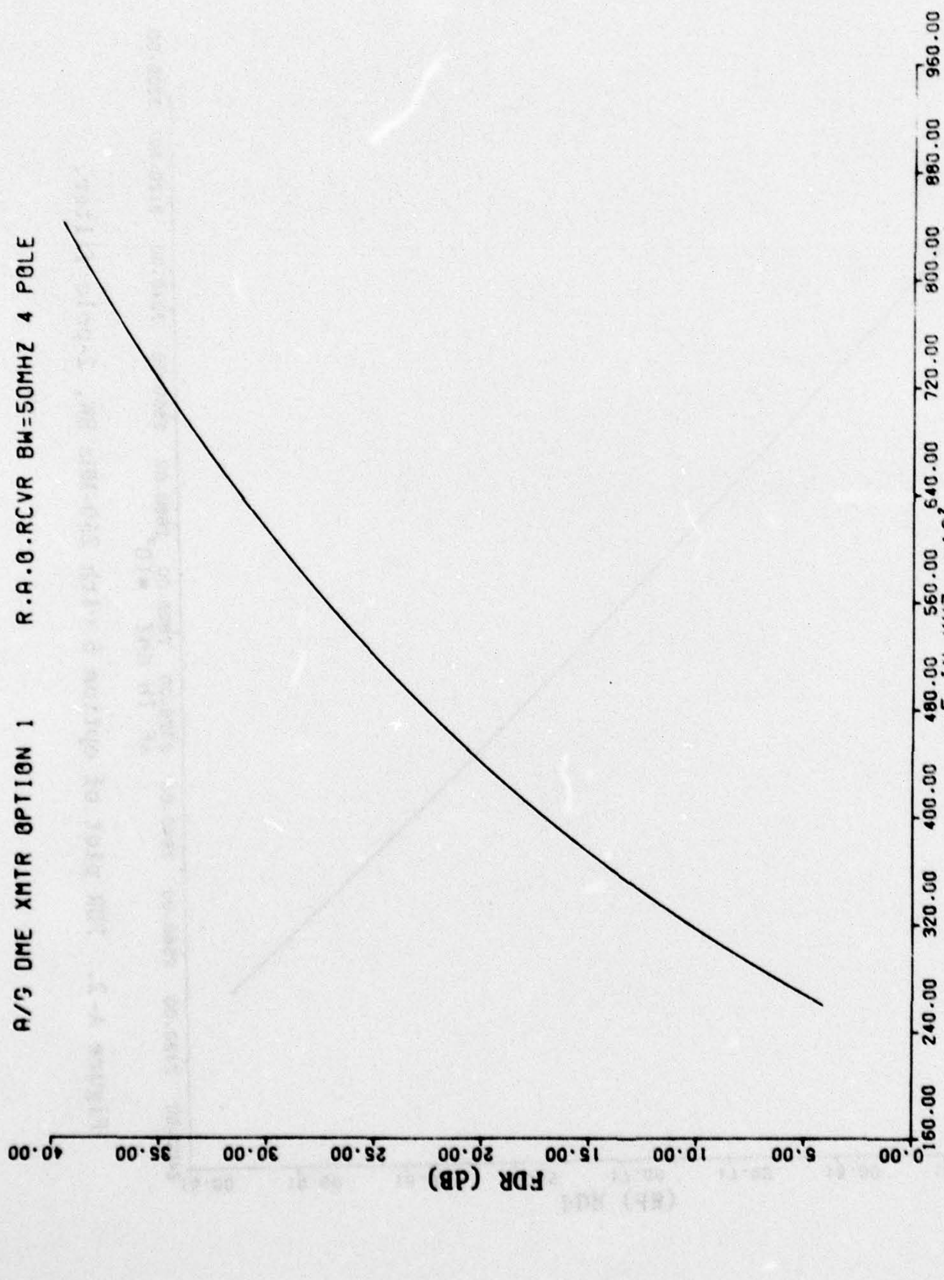

Figure A-3. FDR plot of option 1 with 50-MHz BW, 4-pole filter.

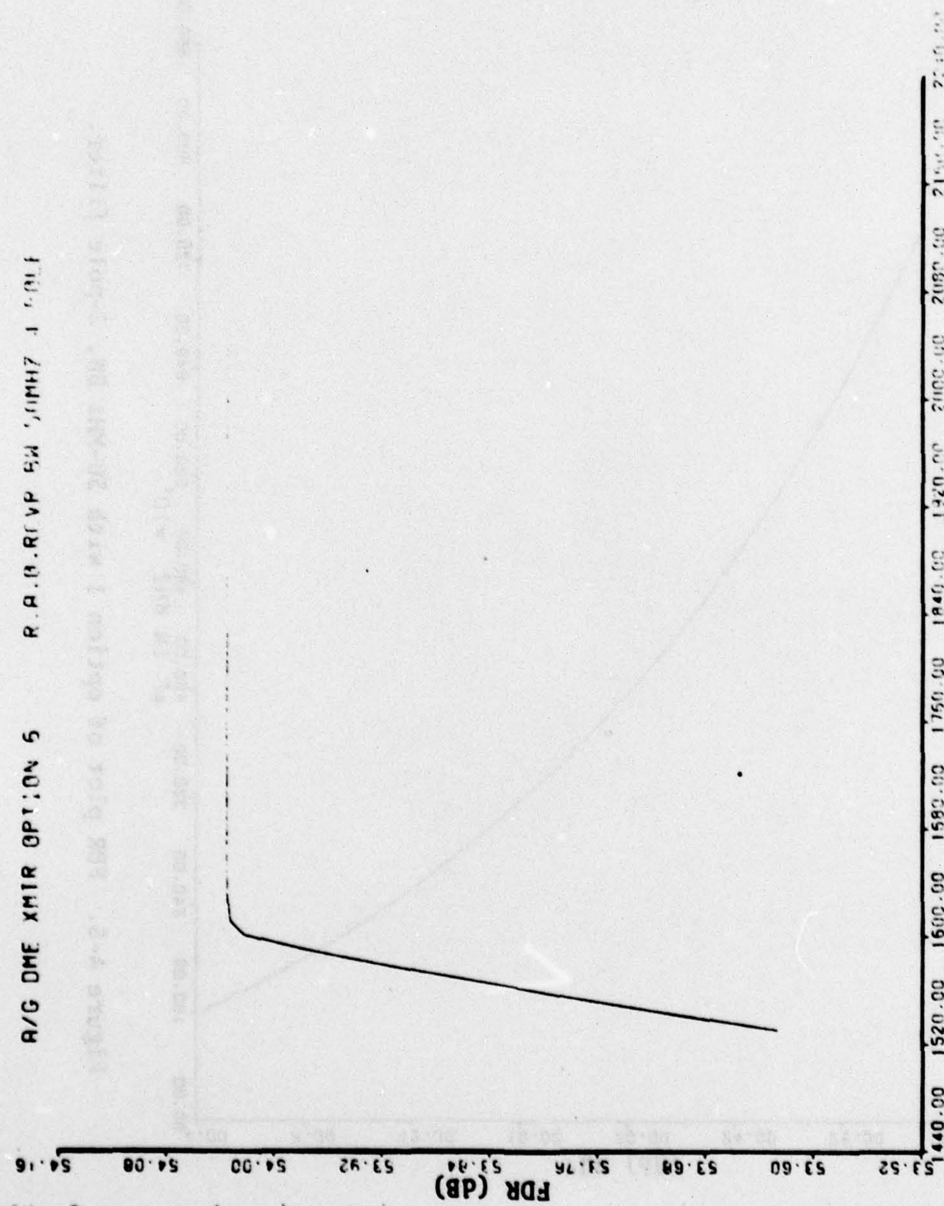

Figure A-4. FDR plot of option 6 with 50-MHz BW, 4-pole filter.

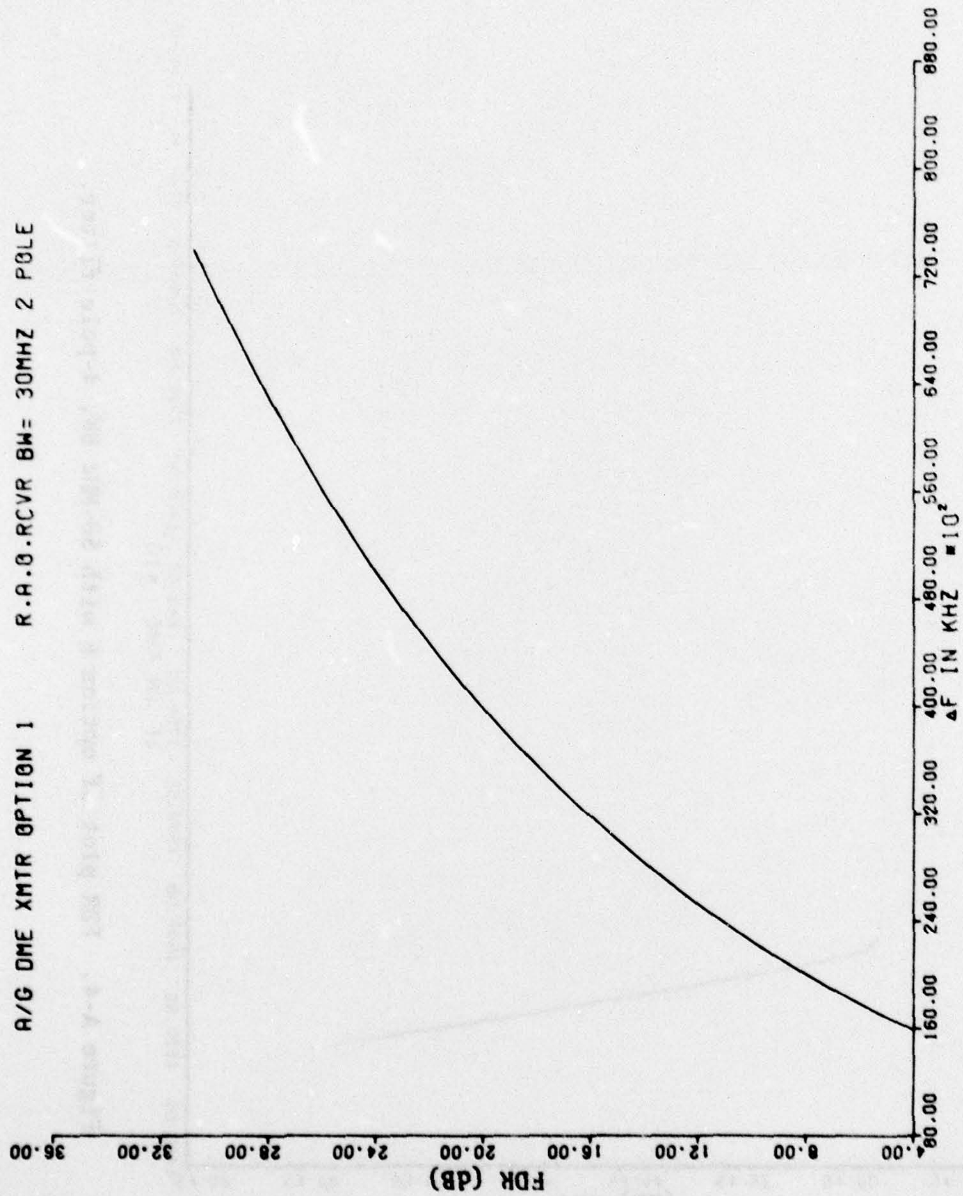

Figure A-5. FDR plot of option 1 with 30-MHz BW, 2-pole filter.

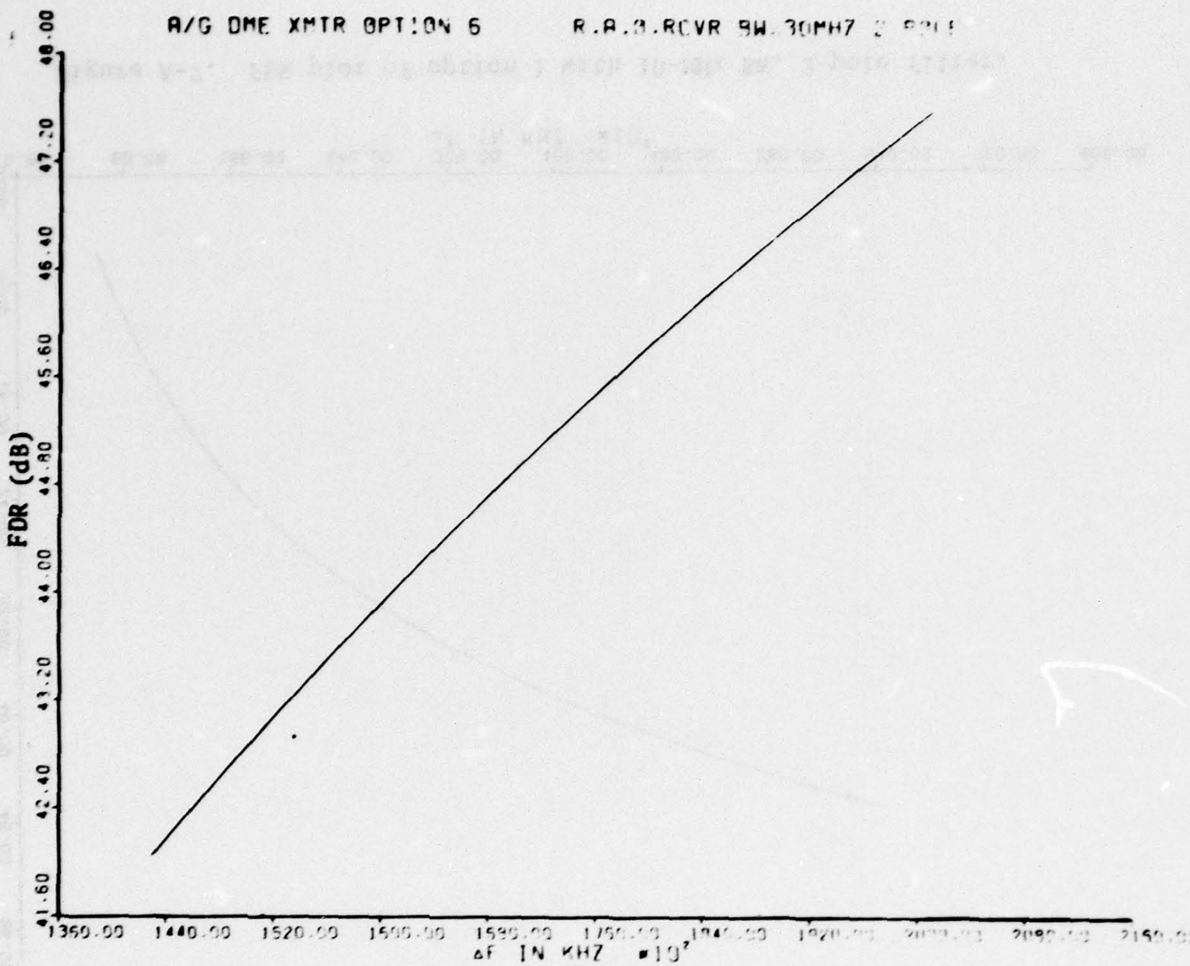

Figure A-6. FDR plot of option 6 with 30-MHz BW, 2-pole filter.

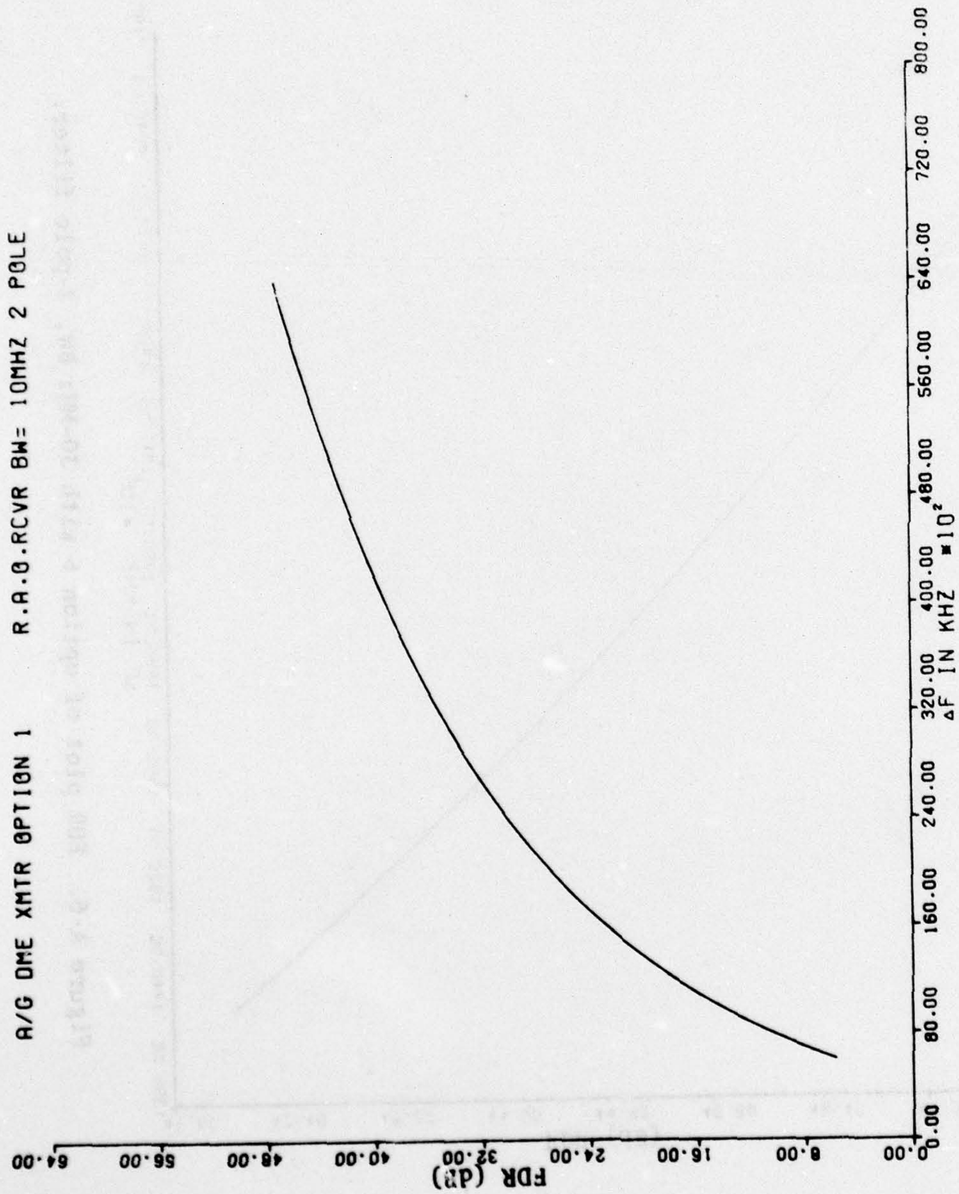

Figure A-7. FDR plot of option 1 with 10-MHz BW, 2-pole filter.

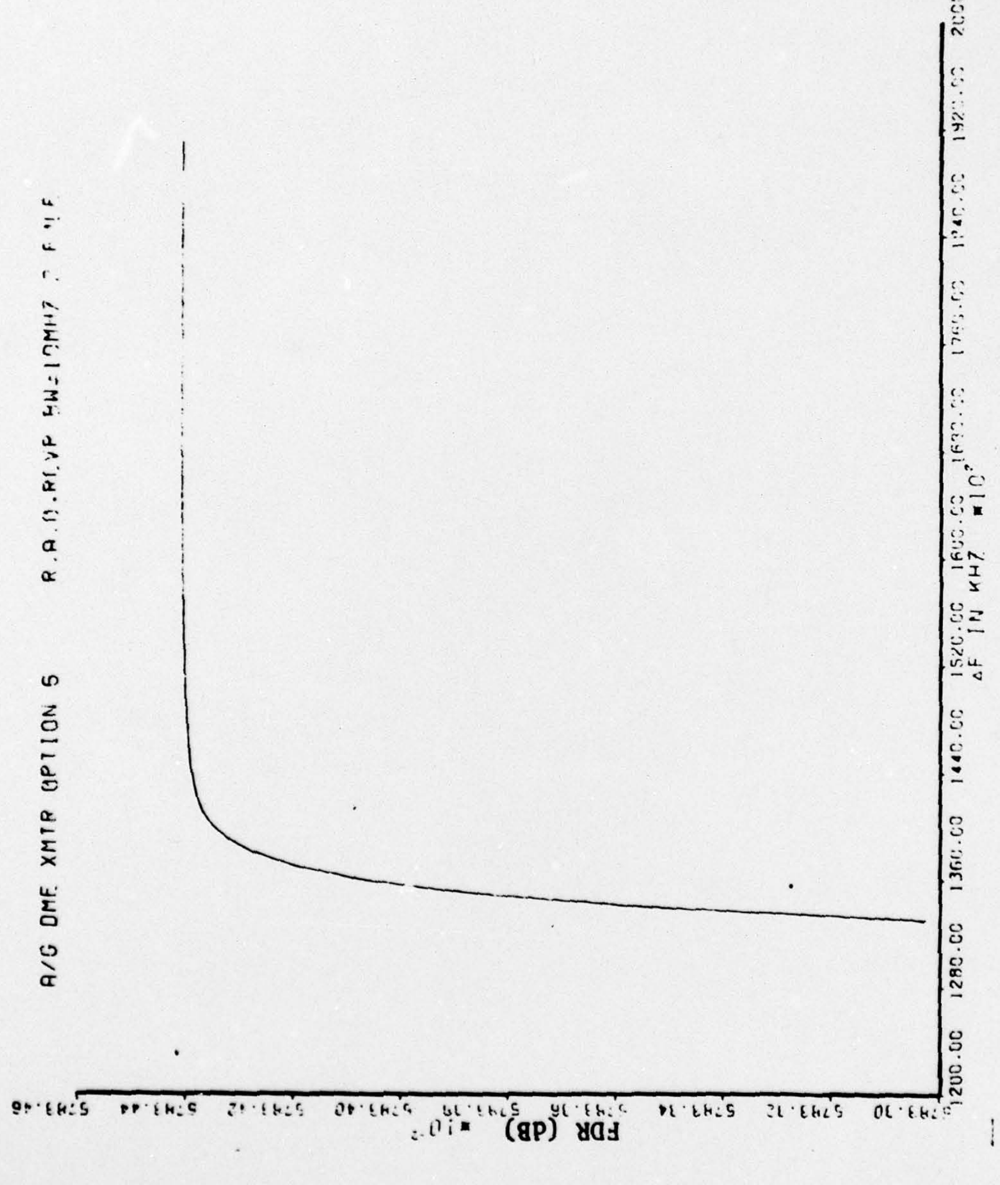

Figure A-8. FDR plot of option 6 with 10-MHz BW, 2-pole filter.

APPENDIX B

FOOTNOTES PERTAINING TO THE 4.990-5.000 GHz RADIO ASTRONOMY BAND AND THE 5.001-5.25 GHz AERONAUTICAL RADIONAVIGATION BAND

Appropriate footnotes from the OTP Manual that specifically pertain to the 4.990-5.000 GHz Radio Astronomy Band, as well as those footnotes that pertain to the Aeronautical Radionavigation band (5.000-5.25 GHz), are reproduced below. In addition, information pertaining to the "quiet zone," as defined in the OTP manual, is included.

FOOTNOTES PERTAINING TO THE 4.990-5.000 GHz RADIO ASTRONOMY BAND

US 74 In the bands 21.85-21.87, 73-74.6, 406.1-410, 1400-1427, 1660-1670, 2690-2700, and 4990-5000 MHz and in the bands 10.68-10.7, 15.35-15.4, 23.6-24, 31.2-31.5, 86-92, 130-140 and 230-240 GHz, the radio astronomy service shall be protected from extra-band radiation only to the extent that such radiation exceeds the level which would be present if the offending station were operating in compliance with the technical standards or criteria applicable to the service in which it operates.

G45 No stations will be authorized to transmit in the bands 21850-21870 kHz, 1400-1427 MHz, 2690-2700 MHz, 4990-5000 MHz, 10.68-10.70 GHz, 15.35-15.40 GHz, 23.6-24.0 GHz, 31.2-31.5 GHz, 52-54.25 GHz, 58.2-59.0 GHz, 64-65 GHz, 86-92 GHz, 101-102 GHz, 130-140 GHz, 182-185 GHz and 230-240 GHz.

FOOTNOTES PERTAINING TO 5.000-5.250 GHz AERONAUTICAL RADIONAVIGATION BAND

US118 In the bands 5.0-5.25 and 15.4-15.7 GHz, a "common system" microwave landing system is planned which is expected to have worldwide application. It is anticipated that operational implementation will begin about 1976. Nationally, such an agreed common system shall have priority over any other system in these bands.

US211 In the bands 1427-1429, 2500-2690 and 5000-5250 MHz and 14.5-15.35, 15.4-15.7, 24-24.05, 31.5-31.8, 84-86, 122.5-130 and 220-230 GHz, applicants for space station assignments are urged to take all practicable steps to protect observations in the adjacent exclusive radio astronomy bands from harmful interference; however, US74 applies.

G54 Aeronautical mobile communications which are an integral part of aeronautical radionavigation systems may be satisfied in the band 1558.5-1636.6 MHz, 5000-5250 MHz and 15.4-15.7 GHz.

WEST VIRGINIA QUIET ZONE

[Taken from paragraph 8.4.9 of the OTP Manual entitled "Coordination of Assignments to Stations (Other than Mobile) to be Located in the National Radio Quiet Zone."]

"In order to minimize possible harmful interference at the National Radio Astronomy Observatory site located at Greenbank, Pocahontas County, West Virginia, and at the Navy Research Station site located at Sugar Grove, Pendleton County, West Virginia, all proposed frequency assignments to stations (including assignments to stations to be established under group authority), other than mobile stations, within the area bounded on the north by 39°15'N, on the east by 78° 30'W, on the south by 37°30'N and on the west by 80°30'W, shall be coordinated prior to authorization with the Naval Research Laboratory, through Mr. A. B. Youmans, Sugar Grove, W. Va. 26815, telephone 304-249-7321, Autovon 934-1850, Ext. 321. Requests for frequency assignment action, including notificaton of stations to be established under group authority, shall indicate that successful coordination has been effected.

For the protection of the Navy Research Station, the field strength at the main site (38°31'16"N, 79°16'36"W) of ground-based transmitters located within the aforementioned zone should be below 0.1 microvolt per meter in the frequency range 50-1000 MHz, below 1.0 microvolt per meter in the frequency range 1000 MHz-10 GHz, and below 10 microvolts per meter in the frequency range 10-1000 GHz for all heights up to 2292 feet above mean sea level (approximately 60 feet above ground at the Navy Research Station antenna). In determining the level of field strength at the Navy Research Station, the instantaneous (time domain) signal of the ground-based transmitter will be measured."

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